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Aircraft Carrier Flight Deck Fire Fighting Tactics and Equipment Evaluation Tests

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Following the crash of an EA-6B aircraft on the flight deck of the USS NIMITZ on May 26, 1981, an extensive research program was undertaken to address possible deficiencies in shipboard fire fighting procedures and systems and to identify potential areas for improvement. The test program included evaluation of existing shipboard equipment such as handlines, the flight deck washdown system and the P-16 fire-fighting vehicle, as well as proposed improvements such as high flow rate monitors (up to 12,000 gpm), hose tie down devices and robots. The effectiveness of both water and Aqueous Film Forming Foam in cooling ordnance exposed to a hydrocarbon pool fire was also investigated. The systems were evaluated in simulated aircraft carrier flight deck fires using a specially-designed debris pile fire as a standard or reference fire and under wind conditions of 0-03 knots. A total of 216 fire tests and 56 non-fire tests were conducted. As a result of this program, a number of actions have been taken including changes in firefighting doctrine that have already been implemented into the Fleet. The effectiveness of existing shipboard firefighting systems, when installed and used properly, was also confirmed. Keywords: Electronic aircraft.

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CONTENTS

CONTENTS (Continued)

CONTENTS (Continued)

FIGURES

TABLES

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The nature of the aircraft carrier flight deck fire problem and the difficulty of providing a realistic simulation of these fires at a land-based test site so that proposed solutions could be evaluated required a considerable degree of dedication, support, patience and just plain hard work from many people. Among those deserving special recognition are:

-The CV Fire Fighting Flag Level Steering Committee (and particularly its chairman, Vice Admiral James H. Webber)

-Naval Weapons Center, China Lake, CA
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-Naval Sea System Command
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AIRCRAFT CARRIER FLIGHT DECK
FIRE FIGHTING TACTICS AND EQUIPMENT
EVALUATION TESTS

1.0 INTRODUCTION

1.1 Background

On May 26, 1981, an EA-6B aircraft crashed into several parked F-14's while attempting to land on the USS NIMITZ (CVN-68). As a result of the crash and the ensuing fire and explosions, 14 persons were killed and 42 injured. Damage was estimated at $60 million of which over $53 million was attributed to destroyed and damaged aircraft.

Fire fighting efforts were initiated immediately after the crash. However, the countermeasures washdown system, which dispenses Aqueous Film Forming Foam (AFFF) through nozzles located in the flight deck, and along the deck edge, was not activated until more than two minutes after the crash. The upwind zones of the washdown system produced only seawater for the duration of the fire due to electrical malfunctions in the AFFF pump circuitry. Meanwhile, the fire was fed by the flow of JP-5 fuel from at least one F-14 aircraft, which had just been refueled prior to being struck by the crashing EA-6B. A total of three F-14 aircraft were involved in the fire, each of which was armed with a Sparrow, a Sidewinder, and a Phoenix missile and an undetermined quantity of 20 mm ammunition. Throughout the fire, hand lines (fire hoses) dispensing seawater were used in an attempt to cool the various ordnance in order to prevent explosions (cook-off). The fire was declared out after a duration of about 19 minutes, and fire fighters moved in to overhaul smoldering debris. Shortly thereafter, a Sparrow missile, which was concealed in the debris, detonated killing two and injuring 29 persons.

The formal Board of Investigation attributed the lengthy extinguishment time to a number of deficiencies in both fire fighting equipment and techniques. The following hindrances to rapid fire extinguishment were identified:

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1. failure of upwind washdown zones to produce Aqueous Film Forming Foam (AFFF);

2. loss of deck edge nozzles in the fire area (destroyed in the initial crash);

3. inability to get hose teams, MB-5, and P-16 fire fighting vehicles upwind of the fire;

4. possible dilution and washing away of AFFF by salt water discharge from hose and malfunctioning upwind washdown zones;

5. major debris from wrecked aircraft which shielded the fire and possible blocking of flush deck nozzles in the fire area;

6. six out of nineteen flush deck nozzles in the fire zone were internally clogged prior to the incident;

7. delay in activation of washdown system;

8. failure to nurse the P-16 fire fighting vehicle;

9. possible involvement of combustible aircraft structural materials (titanium and composite fibers);

10. ordnance cook-off and intense burning of ordnance filler;

11. reaction of other aircraft components (liquid oxygen, hydraulic fluid, engine oil, ejection seats, explosive jettison devices, upholstery, cushioning, harnesses, belts, plastic hoses, insulation, cables, etc.);

12. presence of a large running fuel fire under at least one aircraft due to fuel tank rupture.

The findings of the Board of Investigation were presented to the CV Fire Fighting Flag Level Steering Committee (FLSC) which directed the development of a plan of action. The purpose of the plan would be to address certain voids in the Navy's knowledge of flight deck fire fighting, to substantiate the findings of the NIMITZ investigation, and to identify possible improvements to flight deck fire fighting systems and procedures. The points identified in the plan of action, relative to the tests reported herein were:

1. effect of simultaneous water and AFFF application (extent of dilution, washing away, and impact on extinguishment time);

2. proper hand line stream application techniques for fires involving ordnance (weapons cooling vs. fire extinguishment);

3. propensity of AFFF to insulate or cool ordnance;

4. effect of debris on washdown system and AFFF hand line performance;

5. effect of long pre-burn and large running fuel fires;

6. ability of AFFF to extinguish running fuel fires;

7. relative effectiveness of 2-1/2 in. and 1-1/2 in. AFFF variable pattern nozzles;

8. proper fire fighting techniques for possible titanium ignition in an F-14 crash (deleted later by direction of FLSC, being studied separately);

9. effect of full fire involvement of "ready for flight" aircraft (deleted later by direction of FLSC, being studied separately).

The plan also called for the restoration and alteration of the aircraft carrier mini deck fire test site at the Naval Weapons Center (NWC), China Lake, California. This site had previously been used for flight deck fire fighting tests [1, 2]. Simulation of the unique fire conditions during the USS NIMITZ incident required preliminary, small-scale ordnance screening tests by NWC. These tests selected representative ordnance types [3] that were to be used in the subsequent large-scale fire tests. Preliminary development of a standardized debris pile to simulate crashed aircraft (see Section 4.4.6) and a device to provide a variable flow, running fuel fire to simulate a ruptured fuel tank was conducted at NRL. The initial plan for the large-scale fire test program addressed the following 6 phases:

Phase 1. Effects of water alone and of water as a dilutent to AFFF in control and extinguishment of fires when using either the washdown system or hand lines

Phase 2. Cooling or insulating effect of applying AFFF versus water to ordnance exposed to a fire

Phase 3. Extinguishing running fuel fires of different configurations

Phase 4. Effect of debris pile on fire extinguishment with additional running fuel fire

Phase 5. Relative effectiveness of 1-1/2 in. and 2-1/2 in. AFFF hand lines under various controlled wind conditions

Phase 6. Fire fighting agents and techniques for combustible metals (continued as a separate program to be completed in 1986)

As a result of later events in the program, the original plan was revised to delete Phase 6, but to add the evaluation of several new approaches to flight deck fire protection. These were:

1. scoping tests to determine the effective range of monitors (water cannons) having flow capabilities ranging from 500 to 12,000 gpm under various wind conditions to simulate side delivery positions (catwalk and island mounting);

2. systematic tests to refine and identify specific hardware and tactical requirements generated from the studies conducted during the scoping tests;

3. concept evaluation tests to develop near term improvements to the flight deck fire protection capability, including increased flow washdown systems, small monitors and the P-16 crash-rescue vehicle;

4. variable height monitor tests to determine the effect of height on the ability of a 6,000 gpm monitor to extinguish a debris pile fire in a 30 kt wind at ranges from 25 to 150 ft;

5. concepts and refinements tests to evaluate portable devices that could be used in a carrier deck fire fighting operation, for example, a hose control device;

6. tests of modifications to the P-16 Navy crash rescue vehicle that improve its fire fighting effectiveness and simplicity of operation.

The high flow monitor concept mentioned in items (1) and (4) was evaluated in response to direction by The Vice Chief of Naval Operations [4].

The Steering Committee's approval of the revised plan resulted in the studies reported herein. These studies include the original tests planned to duplicate the fire conditions that occurred on the USS NIMITZ, as well as those designed to provide improved methods of fire extinguishment and better protection for fire fighters.

2.0 OBJECTIVES

2.1 General Objectives

The general objectives of this program were to conduct large-scale tests to accomplish the following:

1. duplicate fire fighting conditions experienced during the NIMITZ fire;

2. conduct similar tests with procedures and systems operating as designed and compare results with the NIMITZ scenarios;

3. conduct tests which evaluate fire fighting systems and tactics in order to determine near term improvements;

4. determine the effectiveness of high volume, stand-off delivery systems (monitors) for extinguishing pool fires, debris pile fires, and ordnance cooling;

5. determine the effective fire fighting range of monitors with flow rates from 100 to 12,000 gpm in a 30 kt crosswind and in no wind conditions;

6. determine the effect of height on the ability of monitors to extinguish fires at various ranges;

7. evaluate the effects of using an increased flow washdown system on fire extinguishment;

8. determine the effect of flight deck fires on Shrike and Sidewinder missile motors;

9. determine the comparative effectiveness of water and AFFF for ordnance cooling and evaluate the effects on fire extinguishment while diverting a portion of the fire fighting agent to weapons cooling;

10. determine the effect of wind upon fire severity, agent application and fire fighting operations using washdown systems, hand lines and monitors;

11. evaluate various portable devices, such as hose control devices and personnel protective shields to determine their feasibility for shipboard use;

12. evaluate the effectiveness and determine improvements required for, the P-16 crash rescue vehicle;

13. conduct tests of fire fighting systems and tactics for long-term improvements.

2.2 Specific Objectives

The objectives of the test plan as approved by the FLSC were as follows:

1. NIMITZ Tests

    a. determine the decrease in fire fighting efficiency resulting from use of water instead of AFFF in all or part of the flight deck washdown system;

    b. determine the relative effectiveness of water and AFFF for ordnance cooling when using 1-1/2 in. and 2-1/2 in. hand lines;

    c. develop tactics for extinguishing a running fuel fire in a debris pile (Section 4.4.6); i.e., a specifically designed fire test configuration which duplicates many of the features found in the Nimitz incident - see pp. 25-29.

    d. establish time for ordnance cook-off by measuring heat rise and cooling rates of instrumented missile motor cases;

    e. examine the relative fire fighting effectiveness of 1-1/2 in. and 2-1/2 in. hand lines.

2. Monitor Scoping Tests

    a. Phase I

        i. determine the fire fighting effectiveness of monitors with flow rates of 5,000 and 6,000 gpm against the shielded side of a debris pile;

        ii. evaluate the fire fighting effectiveness of monitors with flow rates of 500 to 2,000 gpm against the unshielded side of a debris pile;

iii. determine the fire extinguishing and ordnance cooling effectiveness of single and dual monitor applications.

b. Phase II

i. evaluate the effectiveness of monitors with flow rates from 250 to 2,000 gpm in combating debris pile and pool fires;

ii. determine if the 12,000 gpm monitor can provide significant extinguishing or cooling advantages when operated against the shielded side of a combined debris pile and pool fire from long range (350 ft);

iii. determine how a 30 kt crosswind affects the extinguishment range of monitors with flows of 1,000 and 2,000 gpm against debris pile fires;

iv. determine how varying the angle of streams relative to the wind direction affects extinguishment range in attack on debris pile fires.

3. Systematic Tests of Monitors

a. Phase I (Non-fire Tests)

i. test various flows (from 1,000 to 12,000 gpm) for wind effects on stream reach and confirm previous data (from 100 to 3,000 gpm);

ii. determine the best nozzle elevation angle for effective stream reach;

iii. evaluate the potential for injury to personnel and damage to aircraft by large fire fighting streams.

b. Phase II

i. applying knowledge from Phase I, determine the maximum range for fire extinguishment in 30 kt wind for 100 to 4,000 gpm flow rates against debris pile fires;

ii. determine the ability of a 1,000 gpm erectable monitor (at 30 ft height) to extinguish a debris pile fire.

4. Concepts Evaluation Tests

   a. evaluate the performance of higher flow washdown systems (60 to 250 gpm per nozzle) against debris pile fires as compared to the existing 30 gpm per nozzle design;

   b. evaluate the existing and higher flow washdown systems from the upwind zone only in extinguishing a pool fire;

   c. evaluate the feasibility of using tied down hose control devices to direct hand line streams against debris pile fires in order to minimize personnel exposure to weapons cook-off;

   d. determine the effectiveness of the P-16 fire fighting vehicle with various hardware configurations and extinguishing agents (AFFF, Halon 1211, Potassium Bicarbonate [PKP] dry chemical) against debris pile fires.

5. Variable Height Monitor Tests

Determine the effect of varying the height of a 6,000 gpm monitor in a 30 kt crosswind on fire extinguishing range against a debris pile fire. Determine the effect of varying the angle of the nozzle into the wind.

6. Concepts and Refinement Tests

   a. further evaluation of increased flow washdown systems (60 to 250 gpm per nozzle) on a debris pile fire;

   b. evaluate the use of a remotely controlled robot with a 500 gpm monitor against a debris pile fire;

   c. determine the feasibility of using blast protection shields for fire fighters.

7. P-16 Improvement Test

   a. determine the effectiveness of the P-16 fire fighting vehicle against pool and debris pile fires after modification of the vehicle to increase flow of AFFF and to replace PKP with Halon 1211.

   b. evaluate the relative advantages of 125 gpm and 250 gpm turrets in extinguishing a debris pile fire.

3.0 TESTS CONDUCTED

The total evaluation program consisted of completing nine separate test series. In doing so, a total of 215 tests not including 25 non-fire tests were carried out. The discussion that follows will address the specific type and number of tests completed. Also included is the specific equipment or system parameter involved with each test.

3.1 NIMITZ Tests (October 4-29, 1982)

A total of sixty-four tests were conducted to reach the objectives for the NIMITZ series, as outlined in Section II; namely:

1. Twelve fires were conducted with upwind zone and fire zone washdown systems (operated independently or in combinations using water and/or AFFF).

2. Twenty-three fires using 1-1/2 in. and 2-1/2 in. hand lines operated independently or together with water and/or AFFF.

3. Fifteen fire tests combining washdown systems and hand lines were conducted using water and/or AFFF.

4. Five tests were conducted using monitors, singly and in pairs, flowing 500 and 1,000 gpm, against debris pile fires only.

5. Four tests of 2-1/2 in. hand lines were conducted against a 200 sq ft pool fire containing a simulated missile motor to evaluate the relative effectiveness of both water and AFFF.

6. Four tests were conducted against a JP-4 running fuel fire using AFFF hand lines and Twinned Agent Unit (TAU).

7. One TAU (PKP/AFFF) test was conducted against a JP-5 running fuel fire.

The tests were initially conducted using a 4,000 sq ft pool fire and later included a simulated debris pile with running fuel. Most tests were conducted with wind generated at 15 and 30 kts across the deck. This was done to simulate actual flight deck conditions. However, some tests were conducted at ambient wind conditions of 0 to 3 kts.

3.2 Scoping Tests Phase I (November 29 - December 10, 1982)

A series of monitor scoping tests was planned and completed, based on the positive results of portable monitor tests conducted during the NIMITZ series, and on the interest associated with the potential of using large fixed monitors. These tests were designed to gain knowledge of fire fighting and weapons cooling effectiveness of monitors up to 6,000 gpm against debris pile fires.

Ten fire tests were conducted using fixed monitors and they are listed below:

1. one test of a 500 gpm monitor;

2. three tests of a 1,000 gpm monitor;

3. one test of a 2,000 gpm monitor;

4. one test of a 5,000 gpm monitor;

5. one test of a 6,000 gpm monitor;

6. three tests with two 1,000 gpm monitors used in combination; one of these tests was conducted against a debris pile in a pool fire.

3.3 Scoping Tests Phase II (January 5-14, 1983)

At the completion of Phase I, the monitor evaluation tests were expanded to further strengthen knowledge of monitor performance. These tests expanded monitor flow rates from 250 gpm to 12,000 gpm and also evaluated performance in crosswinds.

Fifteen tests were conducted as follows:

1. a single test of a 1-1/2 in. hand line with variable pattern nozzle, using water only against a debris pile fire. This was conducted to fill a gap in the information obtained in the NIMITZ series (not covered in the objectives of that series, but considered to be a worthwhile effort);

2. three tests of a 250 gpm monitor (two with the monitor directed against the unshielded side of the debris pile fire, and one with the stream directed against the shielded side);

3. five tests of a 1,000 gpm monitor in 30 kt wind at various angles relative to the wind against the debris pile fire (90°, 60° and 30°);

4. one 2,000 gpm monitor test in a 30 kt crosswind against a debris pile fire;

5. three 12,000 gpm monitor tests in ambient winds of 0 to 5 kts (two against a debris pile fire and one against a pool fire);

6. two tests of the combined use of two 1,000 gpm monitors (one against the unshielded side of a debris pile, and one against the unshielded side of a debris pile in a pool fire).

3.4 Systematic Tests Phase I (February 14-24, 1983)

This was the only completely non-fire test series conducted. The tests were designed to determine stream reach at various flows, effect of pressure upon stream reach, and stream coherence under various wind conditions and at various angles to the wind. These tests of various monitor streams established the effective distances that a monitor may be located relative to the debris pile. This information was necessary before fire tests involving wind could be effectively conducted. Reach tests were conducted with no wind, 15 kts and 30 kts of wind. Nozzles were positioned to provide reach data with a crosswind (90° angle to the wind), a 30° angle into the wind, 60° angle into the wind, directly into the wind, and with the wind.

3.5 Systematic Tests Phase II (March 1-11, 1983)

These tests were primarily conducted to establish the ability of various medium size monitors to extinguish a debris pile fire in a 30 kt wind. However, several monitors were tested in no wind conditions. Also tested was the effectiveness of very high flow washdown nozzles on a debris pile fire. A total of twenty-seven tests were conducted and they are categorized as follows:

1. three test of an array of 4 high flow (250 gpm) flush deck nozzles in no wind conditions;

2. four tests of smaller monitors (95-500 gpm);

3. six tests of a 1,000 gpm monitor;

4. five tests of a 2,000 gpm monitor;

5. four tests of a 3,000 gpm monitor;

6. one test of a 4,000 gpm monitor;

7. three tests in no wind conditions of a 1,000 gpm erectable monitor which was mounted at a 30 ft elevation and controlled from ground level;

8. one miscellaneous test in which 6% AFFF was injected into the air stream of a wind machine in an attempt to extinguish a 400 sq ft pool fire.

3.6 Concepts Evaluation Tests (April 5-15, 1983)

This series of 51 tests was conducted to evaluate potential near-term improvements to flight deck fire fighting capability. This involved evaluating in wind and no wind conditions the increased flow washdown systems, hose control devices, selected monitors and the P-16 flight deck fire fighting vehicle. With the exception of five washdown system tests, all were run against debris pile fires. The tests conducted during this period are as follows:

1. seventeen tests of standard flow (30 gpm) and increased flow (60 to 250 gpm) flush deck nozzles in six nozzle and ten nozzle array configurations, in 30 kt winds against both debris pile and pool fires;

2. six tests of hose control devices in various wind conditions;

3. two tests of 1-1/2 in. hand lines to complete data on hand line extinguishment capability;

4. eleven monitor tests of 250 gpm to 4,000 gpm to complete data in various wind conditions not previously tested;

5. one test of the 4,000 gpm monitor under no wind conditions;

6. eleven tests of the P-16 vehicle using its various fire fighting systems in combination to determine their effectiveness in wind and no wind conditions;

7. three miscellaneous tests which included the use of a vehicle mounted monitor; application of stationary "water wall" nozzles as a possible supplement to the washdown system; and the use of a blast shield to protect fire fighters.

3.7 Variable Height Monitor Tests (July 11-15, 1983)

These tests evaluated a 6,000 gpm platform-mounted monitor at various heights above the flight deck. These

tests were designed to assess the feasibility of using a similar device aboard ship and to determine maximum and minimum effective ranges. A total of 17 tests were conducted at distances of 25 to 150 ft from the debris pile, using platform heights of 15 ft, 20 ft and 30 ft. For these tests, the original standard (concrete block) debris pile was replaced by a steel unit having the same outside dimensions and openings, but which could be easily moved from one location to another.

The seventeen tests conducted are as follows:

1. Thirteen tests were conducted where the stream was projected against a 30 kt crosswind.

   a. six tests where the elevation was 30 ft and the distance from the debris pile ranged between 25 ft and 150 ft;

   b. three tests where the elevation was 25 ft and the distance from the debris pile ranged between 25 ft and 150 ft;

   c. two tests where the elevation was 20 ft and the distance from the debris pile ranged between 25 ft and 150 ft;

   d. two tests where the elevation was 15 ft and the distance from the debris pile ranged between 25 ft and 150 ft;

2. Four tests at a 60° angle into a 30 kt wind;

   a. two tests where the elevation was 30 ft and the distance from the debris pile ranged between 45 ft and 140 ft;

   b. two tests where the elevation was 15 ft and the distance from the debris pile ranged between 140 ft and 180 ft.

3.8 Concepts and Refinement Tests (September 8-16, 1983)

This series consisted of 21 additional tests designed to evaluate increased flow washdown systems, hose control devices, portable blast protection shields and a remotely controlled robot with 500 gpm monitor. All tests except one were conducted in 30 kt wind conditions against the original standard debris pile fire. The debris pile was reconfigured by removing walls in instances where the device being tested could not extinguish the fire. This was done in order to

determine the particular device's effectiveness against a less challenging fire.

The 21 tests conducted are as follows:

1. ten tests of standard and increased flow washdown systems with flows of 30 and 90 gpm per nozzle through any of 6 nozzles against various configurations of the debris pile fire;

2. one test of a 1-1/2 in. hand line against a modified debris pile fire;

3. three hand line tests with hose control devices against the standard debris pile fire;

4. two tests of blast shield protection devices against the standard debris pile fire;

5. five tests against the standard debris pile fire using a remotely controlled robot with a 500 gpm monitor.

3.9 P-16 Improvement Tests (November 14-17, 1983)

This series consisted of 10 fire tests designed to evaluate the modifications made to the P-16. These modifications were a result of earlier tests and primarily directed to piping which permitted increased flows to the turret and hand line. Also, the PKP was removed from the twin agent unit and replaced with Halon 1211. This was done in accordance with a previous decision.

The 10 tests conducted are as follows:

1. four tests of the turret and hand line combination against a debris pile fire;

2. one test of a 175 gpm turret placed crosswind against a debris pile fire;

3. two tests of the P-16 twin agent unit against an open front debris pile fire with AFFF and Halon 1211;

4. two tests of Halon 1211 against the open front debris pile fire;

5. one test of a turret and hand line against a combination debris pile fire and pool fire.

4.0 TEST FACILITIES

4.1 Test Sites

The two major test sites utilized for these evaluations were The Naval Research Laboratory's Chesapeake Beach Detachment (NRL/CBD), Chesapeake Beach, Maryland, and The Naval Weapons Center, China Lake, California. The Chesapeake Beach Detachment (CBD) provided a convenient location, only 40 miles from NRL, and the reputation of a proven facility with trained personnel. Therefore, CBD was utilized first to determine small scale feasibility and condition modeling. Following this, large scale tests were conducted at The Naval Weapons Center, China Lake, California. The Naval Weapons Center provided a large simulated flight deck, adequate wind generation capability, and a sufficiently large number of trained personnel.

4.2 Naval Research Laboratory, Chesapeake Beach Detachment (NRL/CBD)

The CBD fire test site is located on the west side of the base and has been utilized for fire testing for over twenty years (see Fig. 1). It has a 2,000 sq ft office and laboratory building that is used for testing various agents including AFFF. Also, a 700 sq ft steel fire test building is available for small scale qualification testing of fire extinguishing agents.

Fig. 1 - Naval Research Laboratory, Chesapeake Bay Detachment Fire Test Facility

Principal fire testing is conducted either on the 3,500 sq ft fire concrete pad located adjacent to the steel fire test building or on the 500 sq ft fire mat located approximately 30 ft north of the main test site. This particular test mat was utilized for development of the running fuel fire, debris pile configurations.

Two fuel storage tanks of 5,000 gal capacity are located underground and two fuel pumps of 100 gpm capacity are located in a pump house adjacent to the 500 sq ft fire mat.

A 750 gpm standard Navy pumper is available to furnish water and AFFF solution. A 6 in. water main supplies water to two hydrants located at the site.

Equipment for generating winds up to 40 kts across the large concrete pad is available.

4.3 Naval Weapons Center, China Lake, CA

The flight deck fire test area is shown in Figs. 2 and 3. This test site is configured as an actual section of an operating flight deck. It is equipped with two washdown zones which provide an upwind zone and a fire zone. Each zone is approximately 4,000 sq ft and contains a typical arrangement of flush deck nozzles as installed on present aircraft carriers. The associated piping for each zone is manifolded to dispense either 6% AFFF solution or water at an application rate of 0.06 gpm/sq ft at 30 psi nozzle pressure. The flush deck nozzle piping for the fire zone is placed in troughs covered with steel plates 20 ft intervals fore and aft. The fire test area is bermed to contain a substrate water layer for fuel leveling purposes. Approximately 1,200 gal of JP-5 fuel was used for each pool fire test. This created a fuel depth in the fire test area of approximately 1/2 in. This depth ensured a total burning time of approximately 4 min which insured that the fires were not starved for fuel and their duration was well beyond any envisioned test scenario. The burning time was calculated based on a nominal JP-5 burning rate of .125 in./min [5].

4.4 Fire Test Support Systems

4.4.1 AFFF and Water Distribution Systems

Since large volumes of both water and 6% AFFF solution were used throughout the entire test program, special distribution systems were required for their storage and transfer. To accommodate flow requirements from 125 gpm to 12,000 gpm, the following pumping configurations were used:

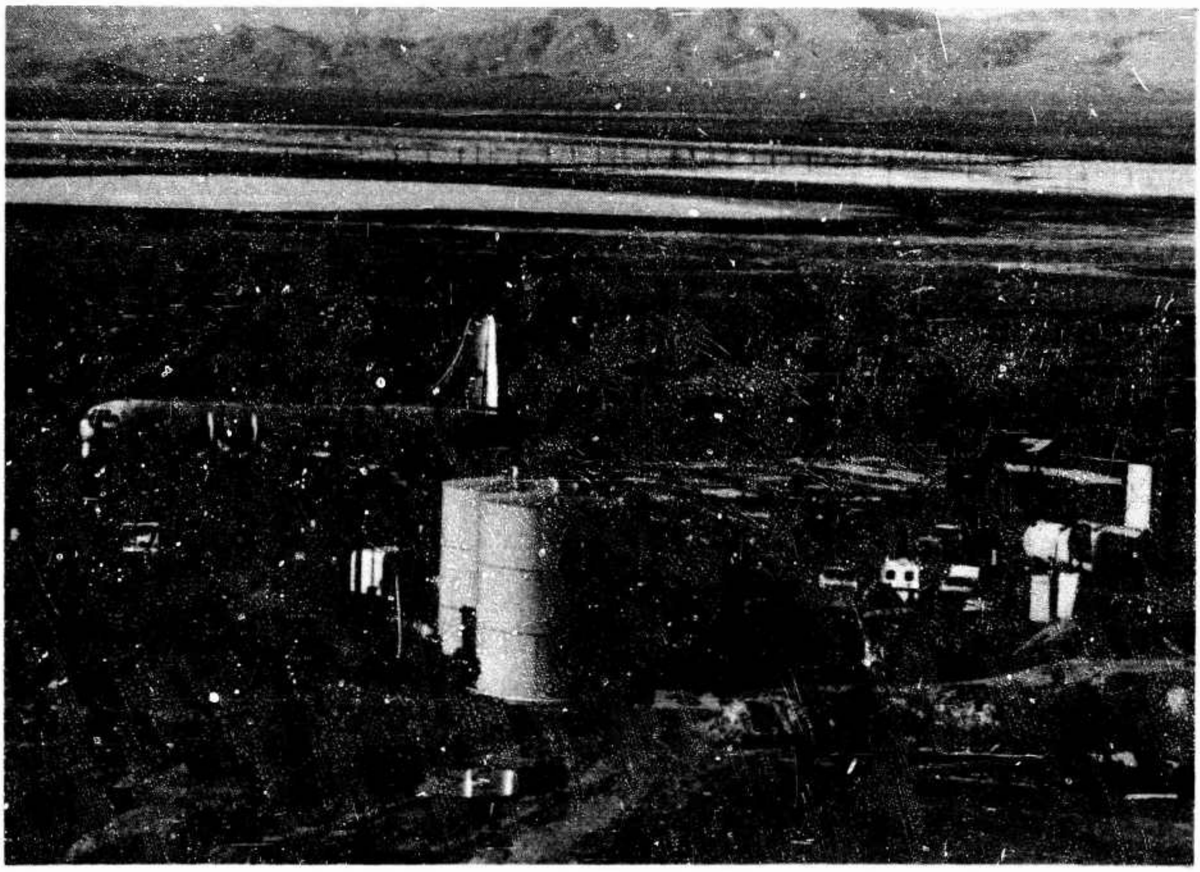


Fig. 2 - Simulated flight deck test site
Naval Weapons Center, China Lake, CA

1. 125 gpm to 1,500 gpm - two 750 gpm standard Navy fire department pumpers furnished by NWC;

2. 1,500 to 6,000 gpm - two 2,000 gpm and one 2,500 gpm gas turbine driven "Firefly" pumping units furnished by the Naval Facilities Engineering Command or leased from KTI, Inc.;

3. 6,000 to 12,000 gpm - eight 1,500 gpm diesel driven pumps leased from Stang Corporation, and two 2000 gpm gas turbine driven "Firefly" pumping units.

Water or AFFF solution was stored in two 64,000 gal tanks, one 10,000 gal tank and two 6,000 gal tanks.

4.4.2 <u>Fuel Distribution System</u>

Initially JP-5 fuel was gravity fed from a 4,000 gal storage tank located approximately 400 ft from the nearest point of the fire test area. Later tests utilized a 4,000 gal fuel truck to supply JP-5.

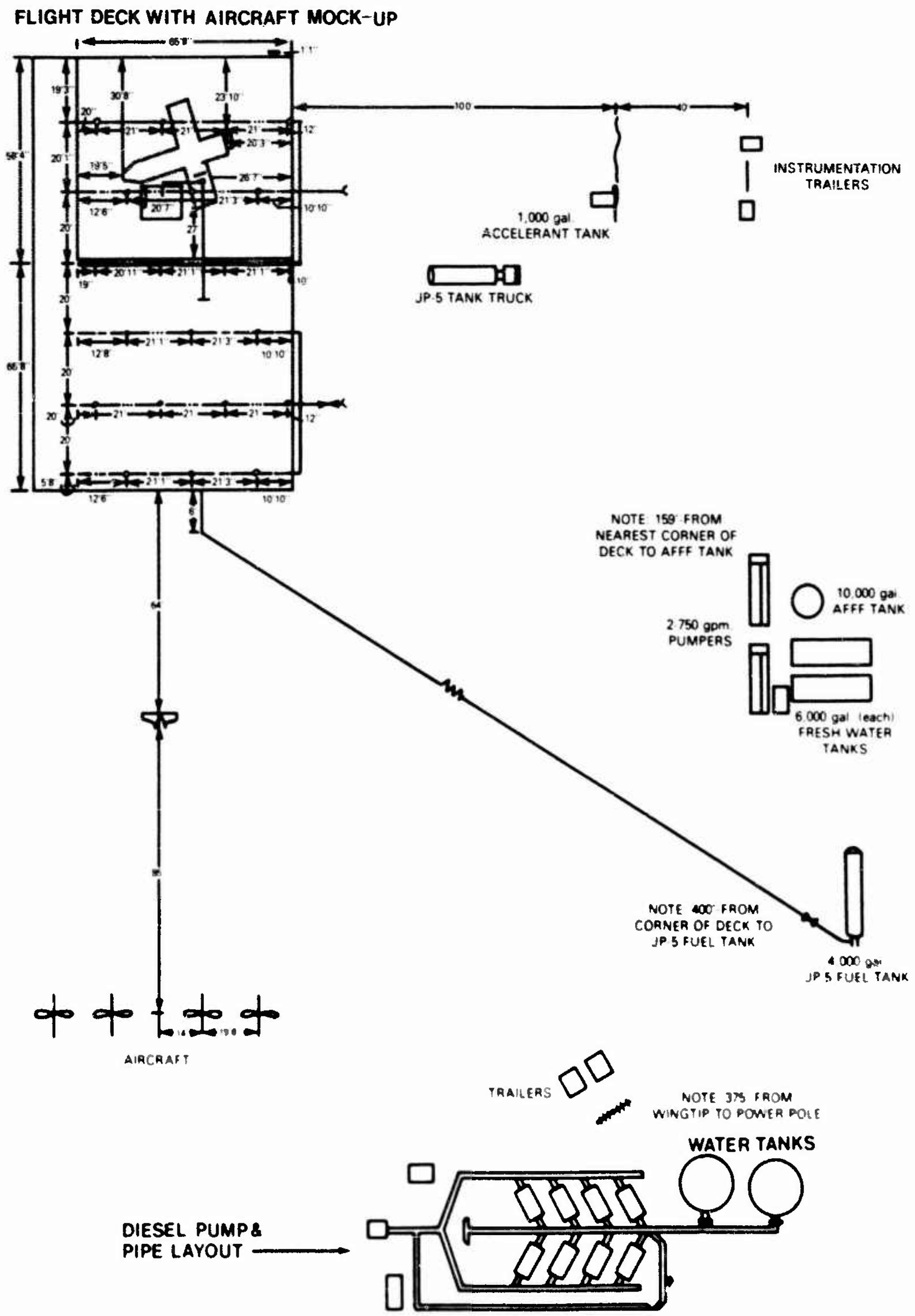


Fig. 3 - Flight deck fire test site layout

(Distance shown on flight deck indicate placement of flush deck and deck edge nozzles.)

Automotive gasoline was used as an accelerant to assure rapid ignition and fire growth for all JP-5 pool and debris pile fires. The accelerant was distributed on the JP-5 either manually by fire fighters using 5 gal cans, or by a special piping system.

4.4.3 Ordnance and Other Instrumentation

Instrumented sand-filled Shrike and Sidewinder missile motor cases were used to simulate live missile motors in order to develop data on heating and cooling characteristics. These ordnance configurations were selected after preliminary studies by the Naval Weapons Center, China Lake (NWC) indicated an adequate correlation [3]. Heating and cooling rates of the cases were monitored by recording the millivolt output from 20 Type K, chromel-alumel thermocouples positioned inside the ordnance and initially located as in Fig. 4. However during Phase I Scoping Tests, the thermocouple locations inside the ordnance were modified to the 10 positions shown in Fig. 5. The number of thermocouples was reduced from 20 to 10 because it was felt 10 thermocouple positions would provide sufficient data. Also this reduction permitted simultaneous collection of thermocouple data from more than 2 cases.

The Sidewinder motor case was always located in the debris pile 3 ft above the deck. However, the Shrike missile motor cases were tested in several different mounting positions, which are as follows:

1. directly beneath the wing of an aircraft mock-up in a pool fire, and approximately 5 ft above the deck;
2. three feet above the deck in a debris pile fire;
3. on the deck in a 200 sq ft pool fire.

Millivolt outputs from the thermocouples were fed into a variable scan data acquisition voltmeter. The voltmeter scan time was set at 2.5 seconds. Output was then sent to a computer where temperature, in degrees Fahrenheit, was calculated and recorded.

Instrumentation was installed during various tests to measure fuel burning rates (by use of load cells), heat flux (radiometers), flame temperature and "air" temperature (thermocouples), and ambient wind speed (anemometer). Agent flow rates and fuel flow rates were also measured using turbine and ultrasonic flow meters. Total agent and fuel used were measured by tank drop. Agent concentration was measured during premixing and confirmed by refractive index (refractometer). These data were acquired during each test

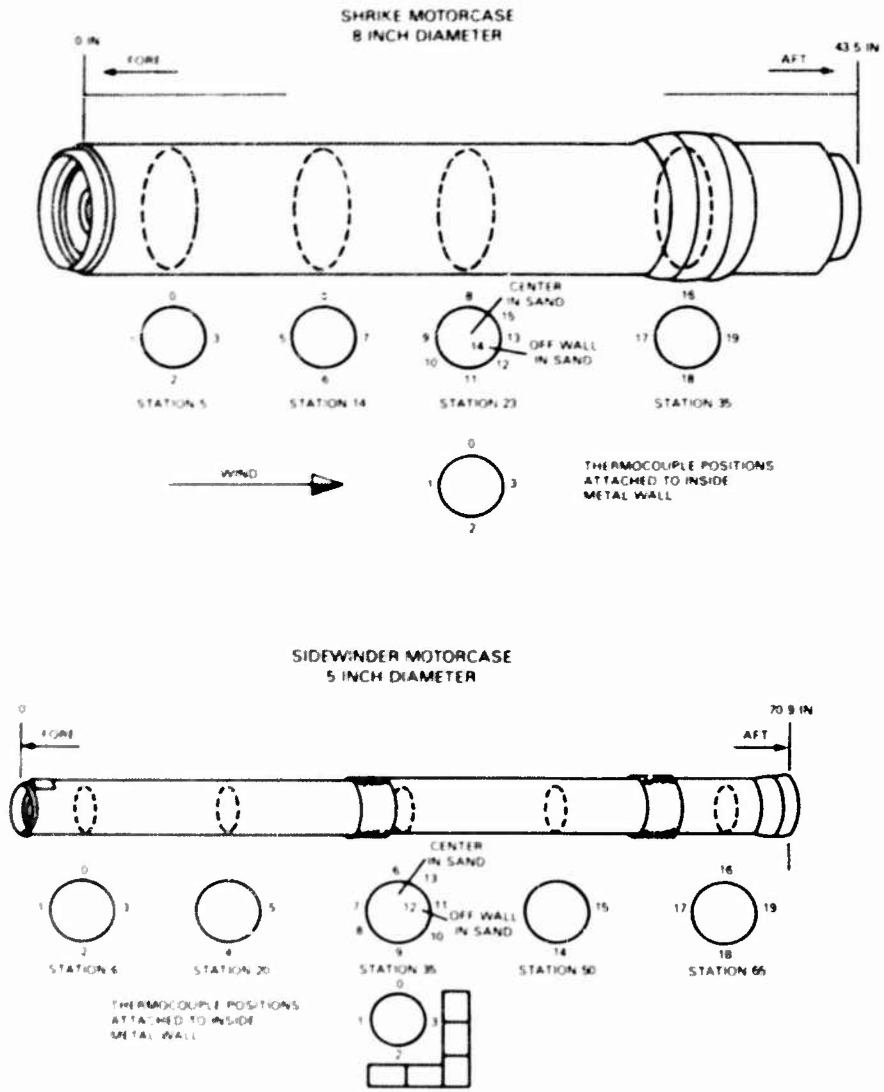


Fig. 4 - NIMITZ test thermocouples locations

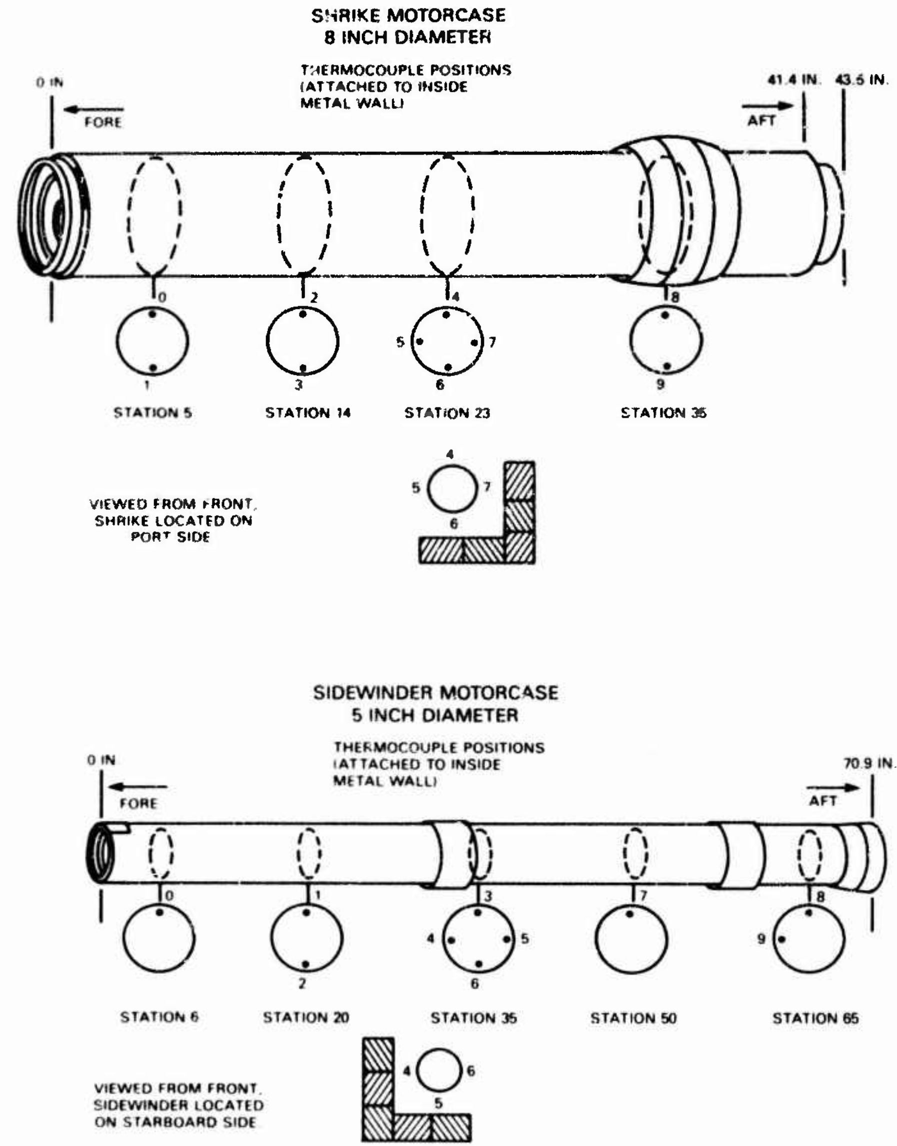


Fig. 5 - Post NIMITZ test thermocouple locations

and later correlated to provide a profile of the fire conditions during fire fighting [5].

4.4.4 Wind Generation

Three types of wind generating equipment were used during these tests to simulate actual flight deck wind conditions. Specific orientation of this equipment appears in Fig. 6. This equipment was used singularly or in combination depending on the purpose of each test. The following three types of equipment were used:

1. A C-97 aircraft providing 4 aircraft engines;

2. 3 airboat engines mounted on 30 ft towers; and

3. 3 truck mounted aircraft engines.

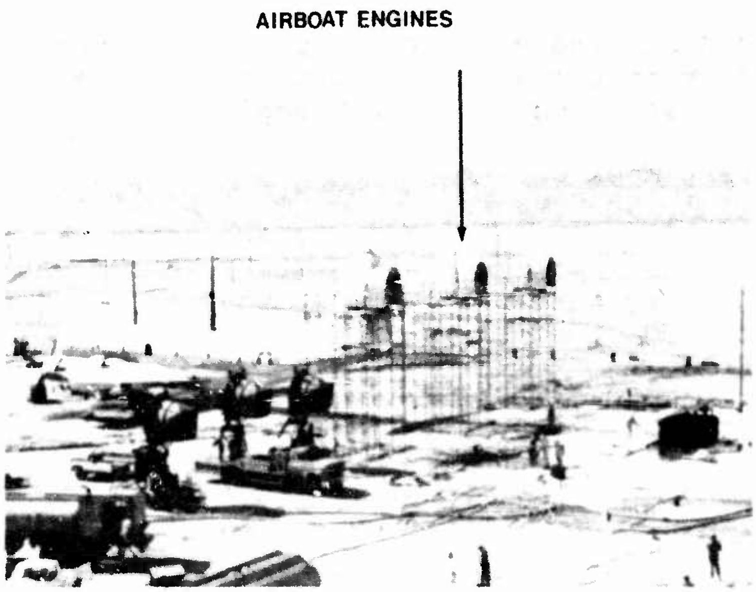


Fig. 6 - Wind generation equipment

The first and primary type consisted of a four engine C-97 aircraft positioned with propellers 210 ft forward of the leading edge of the fire test area. Desired wind velocities were generated by controlling aircraft engine speeds. This equipment alone was capable of providing a range of wind speeds from 10-40 kts. The horizontal width of the wind wall produced by this equipment was sufficient to entirely cover the fire test area. However, the height of the vertical wind wall produced by this equipment was limited to approximately 30 ft.

The second type of wind generating equipment utilized for these tests was three airboat engines. Each engine consisted of a 6 ft propeller driven by a 350 cu in. automobile engine. This provided the capability of generating wind from 10 to 30 kts. These engines were each securely mounted on 30 ft towers and oriented as in Fig. 6. As before, desired wind velocities were obtained by adjusting engine speeds from a remotely located control panel. The purpose of this equipment was to vertically augment the wind generated by the four C-97 aircraft engines.

The third and final type of wind generation equipment was provided by three truck mounted aircraft engines. Each engine drove a 4 ft propeller and was capable of generating wind between 10 to 30 kts. Again, desired wind velocities were controlled by adjusting engine speeds. This equipment permitted horizontal extension of the wind wall produced by the four C-97 aircraft engines.

Wind velocities were checked and verified by measurements taken by anemometers. These measurements were taken over the entire fire test area, prior to each test, to ensure a constant wind velocity. Further anemometer readings were taken from an elevated platform prior to tests which utilized the tower mounted airboat engines.

4.4.5 Aircraft Mock-Up

The aircraft mock-up used for these tests was made of 1/2 in. thick steel boiler plate. Its fuselage was 6 ft in diameter and 36 ft long and the wing span measured 18 ft from wing stub to wing stub, as in Fig. 7.

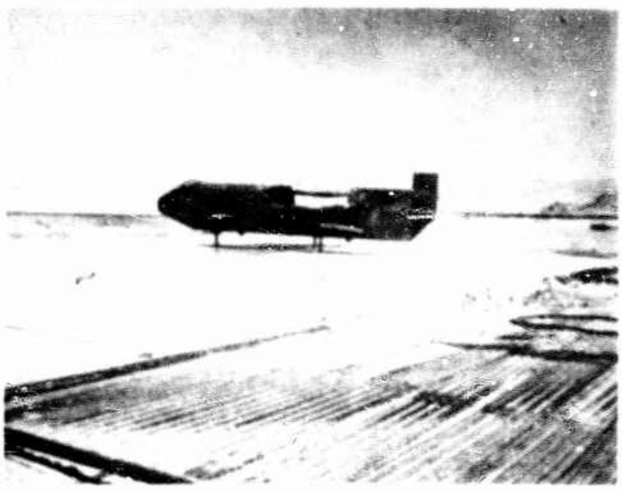


Fig. 7 - Aircraft mock-up

4.4.6 Debris Pile and Running Fuel Fire

To simulate NIMITZ type fire conditions, preliminary efforts focused on developing a standard test configuration that would provide the following features:

- Running fuel fire,
- Deep seated fire,
- Multi-level fire,
- Obstructions & obstacles,
- Partial overhead shielding,
- Ordnance.

The need for such a test configuration evolved from a review of post fire NIMITZ photos such as Fig. 8, which shows the NIMITZ flight deck the morning after the fire. The fire area on the NIMITZ was clearly characterized by a compacted array of aircraft and debris which hampered entry into the seat of the fire.

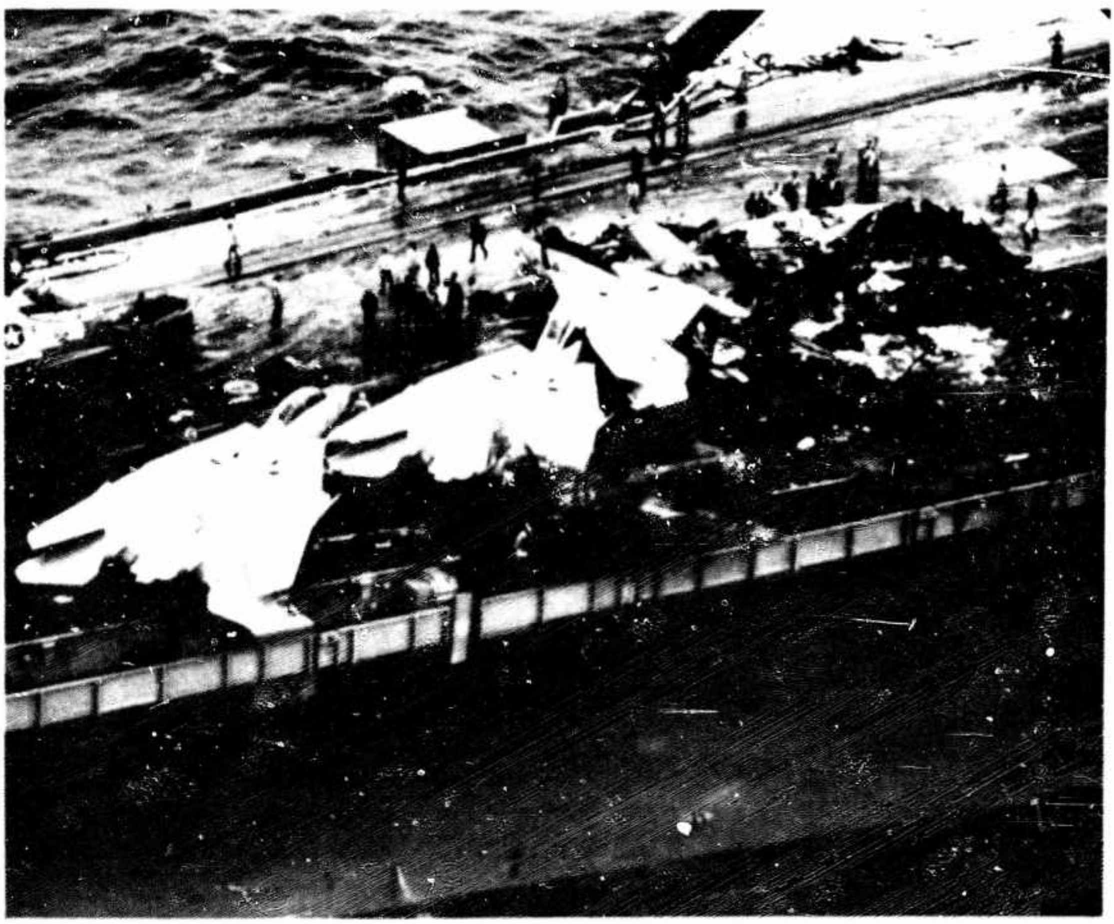


Fig. 8 - NIMITZ flight deck after fire

To simulate this situation, a block house (debris pile) was constructed 9 ft wide x 12 ft long x 5 ft high with a slanted steel roof representing a 12 ft x 15 ft section of fallen aircraft wing. The outer walls were concrete blocks spaced 2 to 4 in. apart and enclosed in a steel I-beam and angle iron frame with vertical supporting rods spaced 8 in. apart. This configuration allowed air and extinguishing agent to penetrate and also provide support to prevent dislodging of the concrete block during agent application. A 3 ft high solid concrete block inner wall was used as a supporting shelf for simulated ordnance (Fig. 9). A JP-5 running fuel array was placed in the debris pile under the slanted roof. The fuel was pumped from a tank truck outside the test area through hose and piping to a 3 in. diameter manifold mounted in a horizontal position 6 ft above the deck. A centrally located slit, 1/4 in. wide and 25 in. long, was provided in the manifold to simulate an aircraft wing tank rupture. The fuel flowed at 50 gpm onto a series of six cascading trays, 3 ft wide x 2 ft deep stacked 5 ft high (Fig. 10). The floor of the debris pile was covered with randomly placed concrete blocks to a height of about 2 ft. This structure provided a running fuel fire with restricted direct access for fire extinguishment.

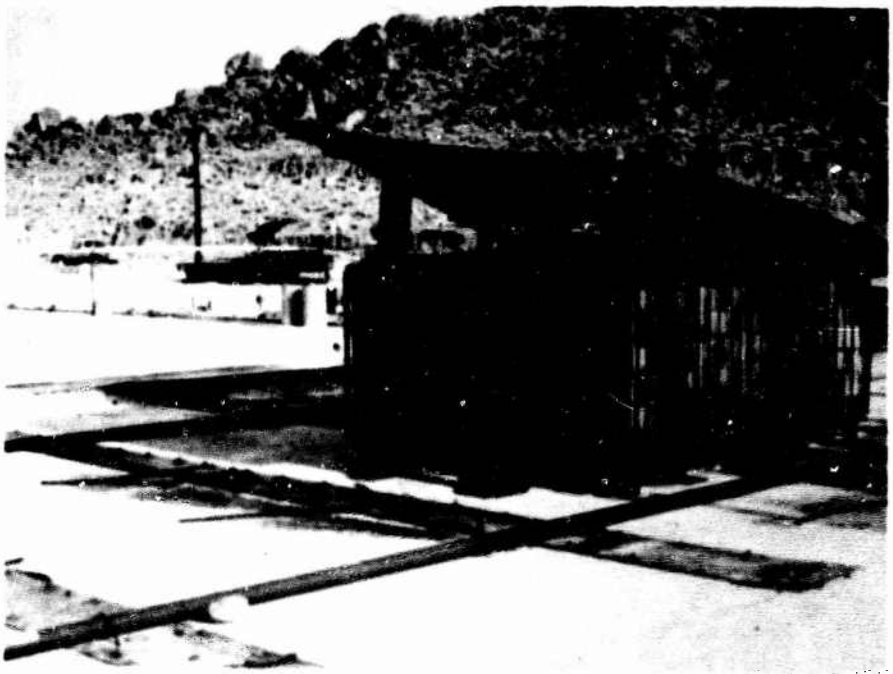


Fig. 9 - Block debris pile

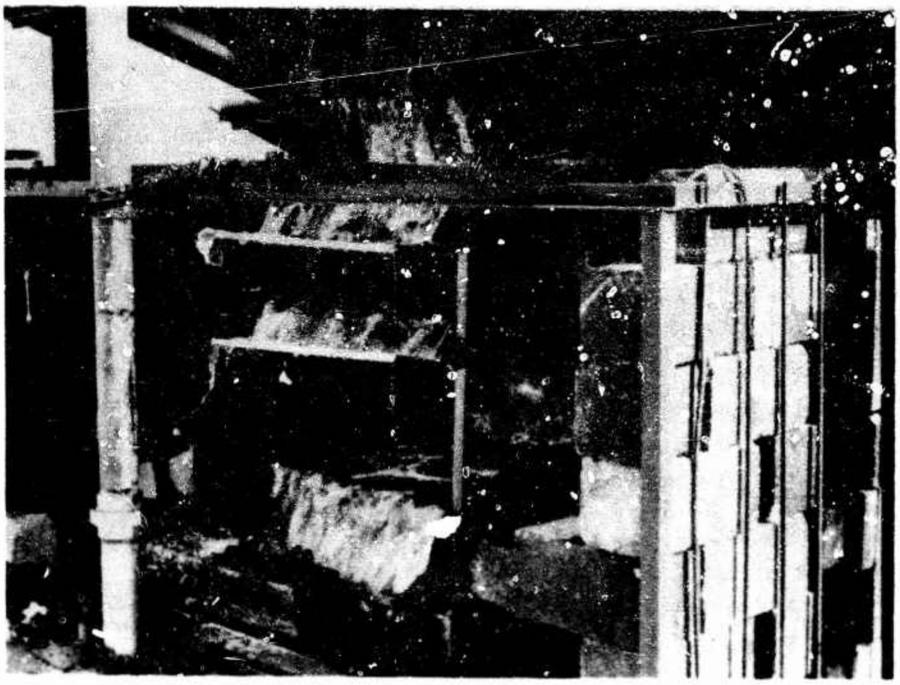


Fig. 10 - Running fuel cascade in debris pile
(Front wall removed to show fuel flow)

The design for these components evolved from a series of preliminary tests conducted at the Chesapeake Bay Detachment of the Naval Research Laboratory. The cascading fuel tray array was devised because it was found that free-fall flow of JP-5 from a height of 6 ft could not be ignited fully by a pool fire. The walls were designed with small spaces between the cinder blocks to allow proper ventilation of the fire, but to partially impede fire fighting. The slanted steel roof and a slit for release of fuel were incorporated to simulate a damaged aircraft wing with a gash in it spilling fuel, further complicating fire fighting efforts. The concept was to have an e⁻ ily duplicated test set-up that would be a challenge tc ..-e fighting capability, but still be realistic.

A second, readily mc able, steel debris pile was used for the Variable Height M. itor tests. The inside configuration was similar o the original debris pile (Fig. 11).

The dimensions cf the standard debris pile (either block or steel) are shown in Fig. 12. It should be emphasized that the debris pile both functionally and dimensionally duplicates the difficult fire fighting problems associated with fires on carrier decks. It provides a standard screening test against which the relative effectiveness of

Fig. 11 - Moveable steel debris pile

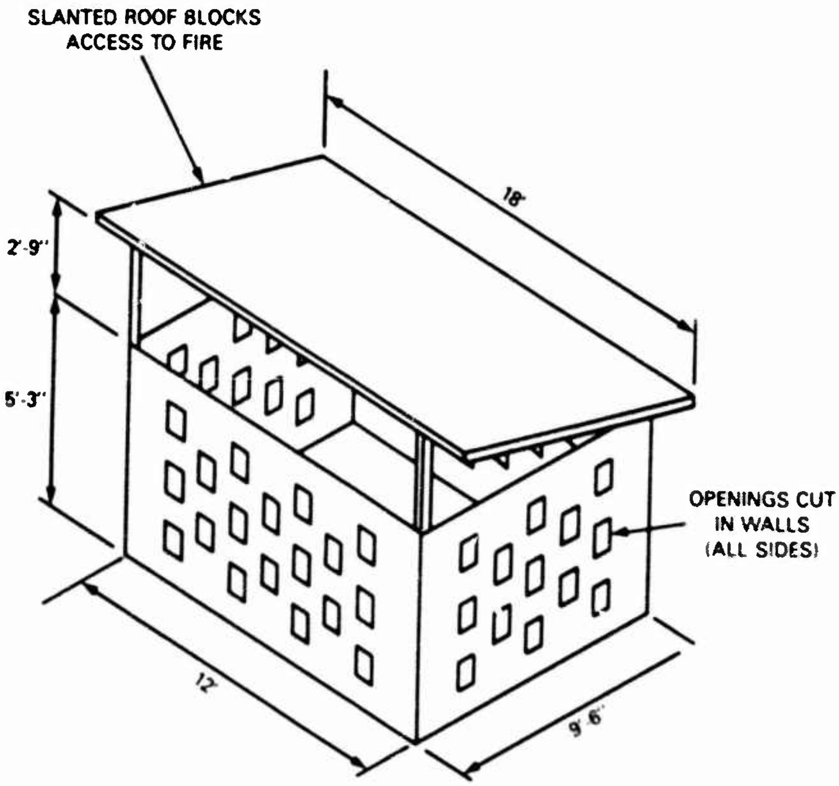


Fig. 12 - Dimensions of steel debris pile

alternative methods and systems can be measured. Therefore, the standard debris pile offers reproducibility, allowing the establishment of a baseline for comparing test results and data.

4.4.7 Variable Height Monitor

A variable height platform was used to simulate potential side mounting positions for monitors on either the carrier's catwalk or the island. The tower mounted monitors permitted evaluation of the relationship of height to effective minimum and maximum ranges in fire fighting situations involving a debris pile fire.

The platform used for monitor mounting measured approximately 6 ft x 12 ft and could be adjusted for a nozzle height from 15 ft to 30 ft in increments of 5 ft. Platform construction permitted supporting a 6,000 gpm monitor (Figs. 13 and 14).

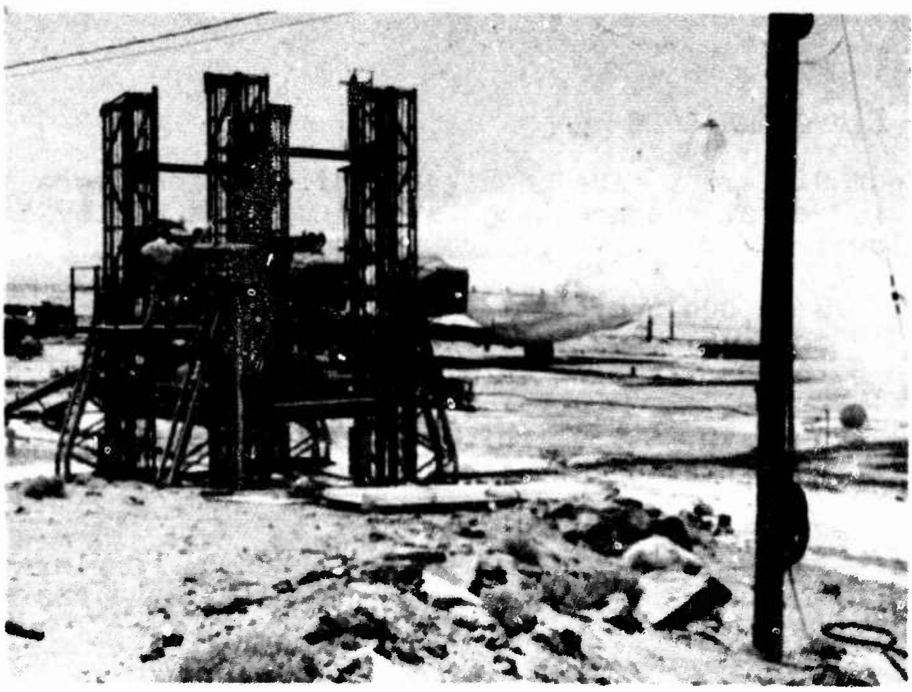


Fig. 13 - Variable height monitor at 15 ft elevation

Fig. 14 - Variable height monitor at 30 ft elevation

4.4.8 Fixed Monitors

Four different fixed monitor configurations were tested. The various mountings and flow rates employed were as follows:

1. a 12,000 gpm, 10 in. Stang monitor mounted on a concrete base and fixed at one location 350 ft from the debris pile (Fig. 15).

2. an 8 in. Stang monitor mounted on a flatbed trailer with nozzle flow ranging from 1,000 to 6,000 gpm (Fig. 16).

3. two 4 in. Stang monitors mounted on trailers with nozzle flow rates ranging from 500 to 3,000 gpm (Fig. 17).

4. a 1,000 gpm monitor mounted on an erectable 30 ft tower (Fig. 18).

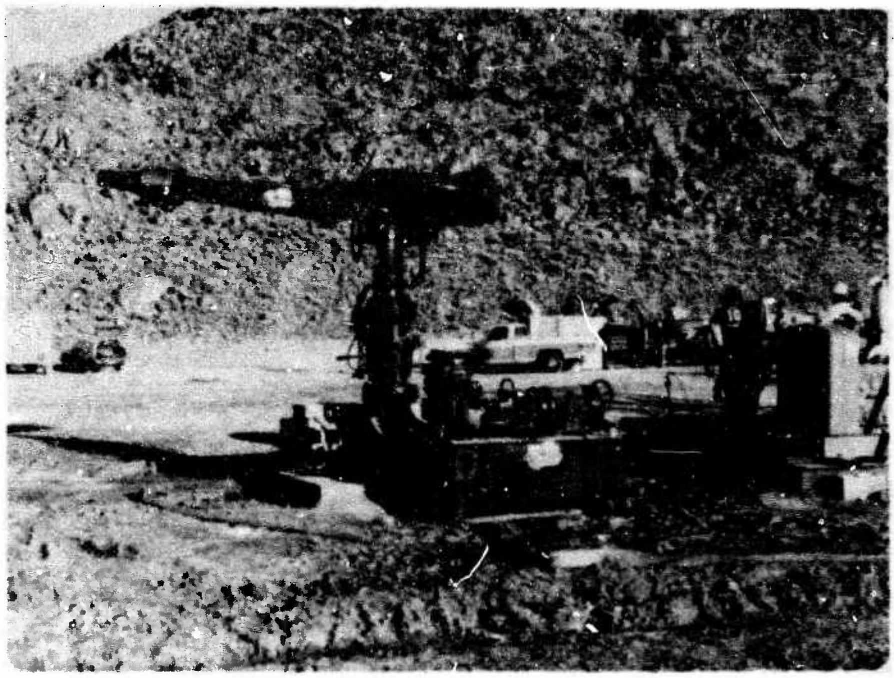


Fig. 15 - 12,000 gpm monitor on a fixed base

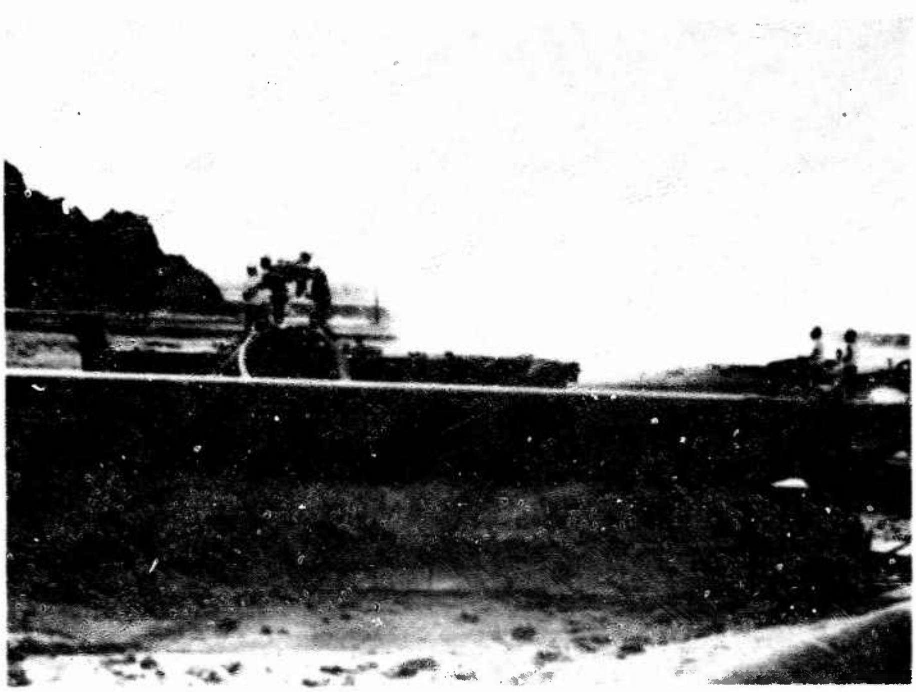


Fig. 16 - 1,000 to 6,000 gpm monitor

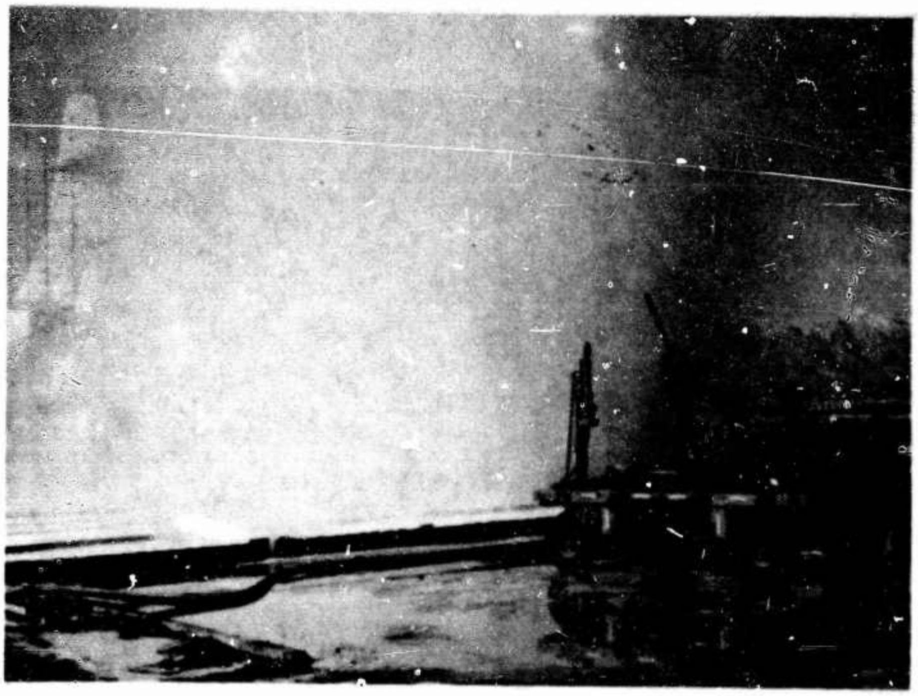


Fig. 17 - 500 to 3,000 gpm monitor

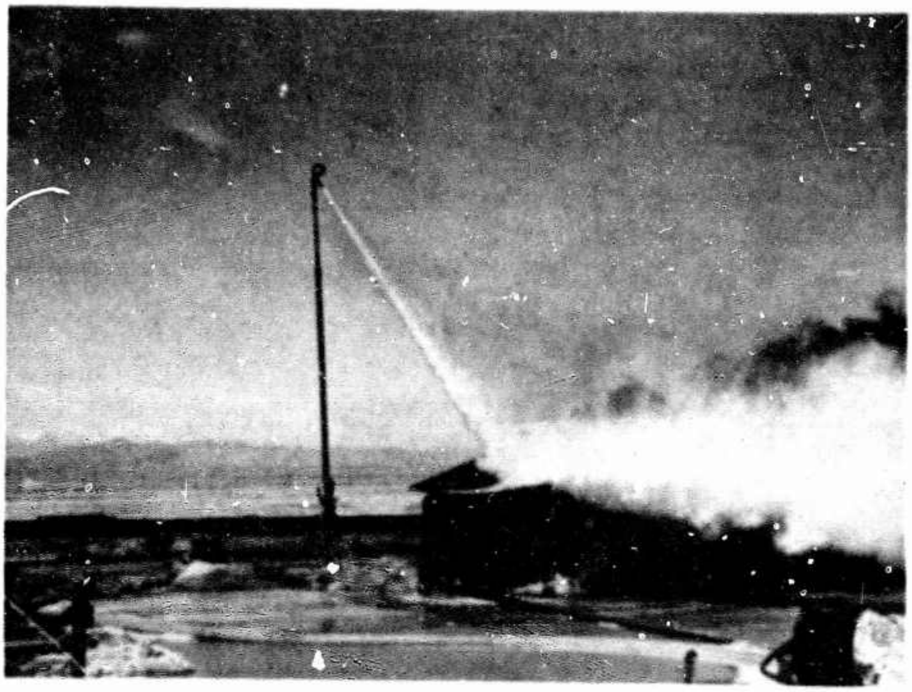


Fig. 18 - 1,000 gpm monitor mounted on a 30 ft erectable tower

5.0 TEST PROCEDURES

Test procedures were defined and standardized to ensure personnel safety and to allow collection of useful, comparable fire test data.

5.1 Safety

Standard safety procedures were developed and followed to avoid injuring personnel or damaging equipment. This was especially critical because at least 40 people were involved in each of the tests, with as many as 20 observers.

5.2 General Information

Prior to any fire testing, AFFF solution was premixed and proper AFFF concentrations were confirmed by refractometer measurements. Sufficient premixed AFFF solution was maintained at all times to assure fire extinguishment with a substantial safety margin. When AFFF and water were interchanged in the same system, the previous agent was thoroughly flushed out with the new agent prior to conducting the next test.

A 'no fire' practice walk-through was conducted prior to each type of fire test. At this time all equipment was checked and participants were briefed on strategy. Also, key team members were in voice contact provided by portable VHF radios. Fuel for pool fires was monitored by a flow meter assuring that approximately 1,200 gal was applied to the deck. This quantity provided approximately four minutes of burning time. This insured that the fuel was never exhausted prior to test completion. Running fuel was applied to the cascade at a rate of 50 gpm for 60 seconds prior to ignition. This was done in order to saturate the debris pile.

In debris pile and combined debris pile and pool fires, the fuel truck was connected to the manifold and fuel allowed to flow for the duration of the test. At completion of agent application, fuel flow was continued to determine if the fire would reignite. Unburned fuel was flushed off the deck into a holding pond located approximately 250 ft to the rear of the deck.

5.3 Accelerant and Ignition

Automotive gasoline was used as an accelerant (priming fuel) in all tests to assure rapid and complete ignition of the JP-5 fuel. In the NIMITZ tests, where practically all of the pool fires were conducted, a 3/4 in. pipe was run across the front edge of the deck with a nozzle every 12 ft and one nozzle on each side placed 12 ft from the front edge of the

deck. Accelerant was applied for one minute at 15 gpm and spread approximately 15 to 20 ft from the nozzle. In later tests, pool fires were ignited using accelerant that was dumped from three 5 gal cans along the front edge of the pool and then ignited using hand held torches. In debris pile only fires, one 5 gal can of accelerant was dumped over the top of the side wall and one along the upwind side at the bottom of the front wall. Ignition was by hand held torches.

5.4 Missile Instrumentation

Thermocouple data were collected in all fire tests on one or more missile motor cases to determine heat rise (maximum temperature minus temperature at agent-on), and rate of cooling under various fire and extinguishing conditions. Sidewinder and Shrike instrumented motor cases were available for the tests. Data were collected at 2.5 second intervals, stored on a disc, and a temperature vs. time curve plotted for each thermocouple. These graphs were then used to select data points to calculate the total heat rise and cooling rates of ordnance and to determine if and when ordnance cook-off would have occurred [3].

5.5 Generated Wind

Tests conducted with zero wind were used for initial evaluations of new equipment or procedures and for stream reach tests. However, most flight deck fire tests required 15 or 30 kt winds. It was determined that ambient wind conditions over 5 kts in any direction other than in the direction of the generated wind, did create conditions which invalidated test data. Therefore, ambient wind below 5 kts was disregarded. Tests adversely influenced by severe ambient wind conditions were generally repeated and are noted in the data tables.

As previously discussed, wind generation was provided by a C-97 aircraft, three truck mounted aircraft engines, and three airboat engines.

5.6 Test Sequence

The following sequence of events generally applied to all fire tests:

A. Smoking lamp out, road blocks up, MB-5 emergency vehicle manned.

B. Record ambient temperatures of fuel, extinguishing agent, air and ambient wind conditions.

C. Start pump engines.

D. Start C-97 aircraft (A/C) and other wind generator engines.

E. Commence fueling.

1. Applying 1,200 gal JP-5 from fuel trucks onto the deck for pool fires required thirty minutes.

2. The standard debris pile fire whether alone or combined with a pool fire, always had 50 gpm running fuel cascading down six special trays inside the pile.

3. After initial fueling was complete, the A/C engines were set to reverse to return fuel to level depth on deck. Running fuel cascade started in debris pile when appropriate.

F. Apply accelerant through pipe systems for pool fire or by 5 gal cans. Torch man in position.

G. Upon signal from test director, ignite fire, start camera, audio and video tape recorders, and weapons instrumentation.

H. Wind generators go to predetermined RPM required for 15 or 30 kts as directed.

I. Instrumentation leader informs test director when 500°F mark has been reached on a missile motor case thermocouple (during NIMITZ tests only, after which 60 second pre-burn was used).

J. Test director signals "agent on". Commence fire fighting. Continue until fire extinguished, or until test director signals test termination.

K. Shut off fuel for running fuel fires and extinguish any remaining fire on or off the deck.

L. Shut down wind generation equipment and agent supply pumps.

M. Log temperatures, flow rates, agent quantity used, fuel quantity used, control and extinguishment times, and any other significant data recorded during test.

N. Evaluate results, record comments of fire fighting team and key observers.

6.0 RESULTS AND DISCUSSION

6.1 General Analysis and Presentation of Data

The general approach was to conduct a single fire test under a specific set of conditions (system, agent, wind, tactic, type of fire, pre-burn, weapon location) so that results for various sets of conditions could be compared. Individual tests were repeated when something went wrong (e.g., ambient wind affecting fire or broken fire hose), for demonstration purposes, or where results were contrary to knowledge from previous tests. Data from all tests are recorded in Appendix A. In the following text, where the comparison of performance is discussed, the most representative test is presented in cases where duplicate tests were run.

6.2 Weapons Heating, Cooling and Cook-off

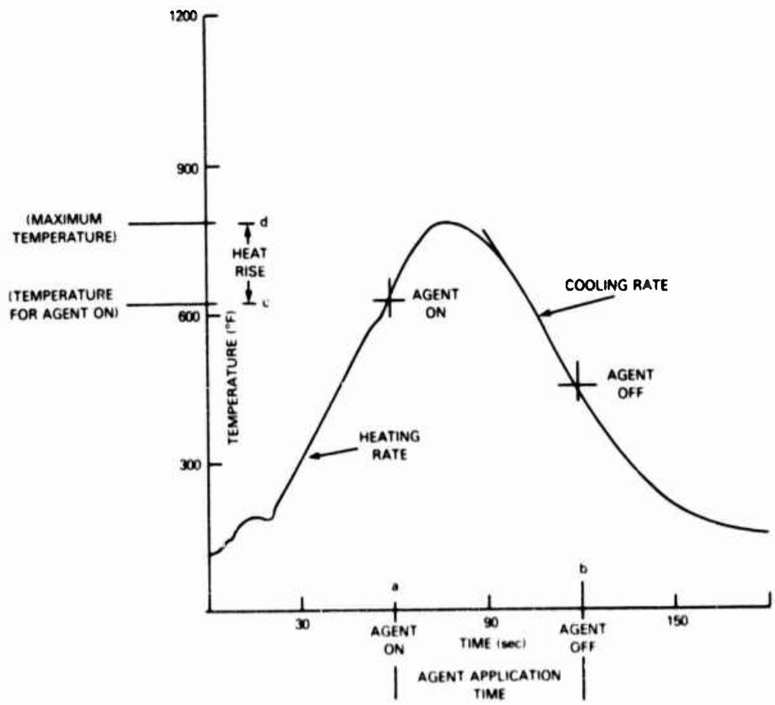
Sand-filled missile motor cases were instrumented in order to determine heat rise, cooling rate and the effect of fire fighting efforts on weapons cook-off. Thermocouples were located on the inside surface of the motor case. Two types of motor cases were used -- the Shrike and the Sidewinder. In some fires, more than one Shrike motor was used. The locations of the Shrike varied depending upon the type of fire, but the Sidewinder was always located in the debris pile (Figs. 4 and 5 in Test Facilities Section).

Weapons cook-off experts disagree on temperature limits for declaring a weapon "cooked-off," and hence, for deciding whether or not fire fighting and weapons cooling measures are effective in preventing cook-off. Based upon the most prevalent opinion, 650°F on thermocouples in the instrumented weapons was selected as the point where a weapon cooks-off [6].

Care must be taken to analyze all data from each fire test before drawing conclusions regarding the effectiveness of agent or technique in that test. For example, in many cases the weapon would have cooked-off before fire fighting began or, due to conditions imposed by the test plan, the extinguishing agent was prevented from reaching the fire and/or cooling the weapon.

The primary data selected for evaluating the effectiveness of fire fighting systems and tactics with respect to weapons cook-off were the heat rise and the cooling rate. Heat rise was calculated by first selecting the thermocouple showing the highest temperature at the time of "agent-on" and then recording the highest temperature reading for the thermocouple after "agent-on" until the

cessation of fire fighting. The difference between these temperatures is the heat rise. The cooling rate was calculated by selecting the single thermocouple within the weapon which demonstrated the most rapid temperature drop after agent-on. The temperature decline recorded was divided by the elapsed time of the decline to give a cooling rate in degrees Fahrenheit per second. In most tests, the heat rise and cooling rate were calculated from the same thermocouple. A typical thermocouple graph appears in Fig. 19.



The data derived from a thermocouple graph includes:

(a) cooling rate,
(b) heat rise, and
(c) heating rate.

Agent application time is shown on the time axis of the graph and is from "a" to "b". Heat rise is shown on the temperature axis from "c" to "d". The slope of the curve is used to determine the heating rate and cooling rate in °F/second.

Fig. 19 - Typical thermocouple graph

In all fire tests the temperature of the weapon began to rise within 10 to 20 seconds after fire ignition. The rate of heating of weapons in pool fires was generally 18 to 22°F/second under all wind conditions. The rate of heating of a weapon in a debris pile fire varied with wind conditions. In zero wind the rate was 8 to 22°F/second. In a 30 kt wind the heating rate was 15 to 30°F/second due to more complete combustion within the debris pile. For a weapon heated above 500°F, air cooling alone will provide a cooling rate of 3 to 5°F/second in a 30 kt wind.

In general, it was observed that where a heat rise of less than 150°F occurred on any weapon, the fire fighting system or tactic performed well enough to control, extinguish and cool sufficiently to have prevented weapons cook-off. Thus, in the tables showing data where "agent-on" occurred below 500°F, cook-off would not have been expected using the 650°F criteria alone. It was obvious, however, that where heat rise was high (150°F or greater), the system or tactic was deficient and under real-life conditions, cook-off probably would have occurred. There are two simplified criteria for analyzing weapons cook-off: a maximum weapon temperature of 650°F or a temperature increase of more than 150°F after the start of agent application.

Other data in the tables show temperatures well in excess of the cook-off criteria of 650°F at the time of agent-on. In these cases, the system or tactic may still have been effective in fire control, extinguishment and cooling if the heat rise was low and the cooling rate was high.

Temperature data were recorded for 329 instrumented weapons in fires attacked by washdown systems, hand lines or monitors. Of the 329, the 650°F cook-off temperature was exceeded 219 times. However, 148 of the 219 would have cooked-off prior to initiation of fire fighting. In pool fires, the wing-hung Shrike motor was shown to have cooked-off in as little as 40 seconds after fire ignition, while the Shrike in the debris pile cooked-off in as little as 80 seconds. The Sidewinder in the debris pile cooked-off in 38 seconds or more. Data were analyzed by NWC personnel and adjusted for motor case liner effects which extended the cook-off times somewhat [7]. NWC reported that the wing-hung Shrike cooked-off in as little as 60 seconds, the Shrike in the debris pile in 90 seconds and the Sidewinder in the debris pile in 50 seconds.

The value of this data is not the difference in hazard between a wing-hung weapon and a weapon in the debris pile, but rather that a good correlation exists between cook-off determinations made by way of the simplified criteria

(650°F max. temp. or 150°F heat rise) and the more detailed analytical techniques applied by NWC weapons experts.

Cooling rate studies [7] performed by NWC show that a weapon whose temperature approaches cook-off and remains high (450 to 600°F) for several minutes can cook-off even though it never actually reaches the 650°F level. Therefore, cooling is extremely important after fire extinguishment, as recommended in the NATOPS manual [8] which requires cooling weapons with hose streams for at least 15 minutes after fire is extinguished.

These conclusions are consistent with all observations and data recorded such as control time, extinguishment time, heat rise, and cooling rate. In addition, these simplified criteria for determining when a weapon would have cooked-off produce results that are in remarkable agreement with cook-off experts' analyses [6,7].

In summary, cook-off of missle motors will occur when the inside of the motor case reaches 650°F. In a JP-5 fire this will occur in 1 to 2 minutes. Heating will begin 10 to 20 seconds after ignition at a rate of 8 to 22°F/second in a debris pile fire. In a pool fire ordnance will heat at a rate of 18 to 22°F/second.

6.3 Washdown Systems

Washdown system tests were run to evaluate the effectiveness of the washdown systems when employed as designed. During the NIMITZ fire two upwind zones did not produce AFFF as designed, resulting in a dilution of the AFFF in the fire zones.

The washdown systems were tested against 4,000 sq ft JP-5 pool fires, debris pile fires, and combination pool and debris pile fires.

The initial testing began with the washdown systems operating in an "as designed" manner with the upwind zone and the fire zone both discharging AFFF. Each flush deck nozzle discharged 30 gpm at 30 psi. Generated wind speeds were 15 and 30 kts. The systems were manually activated when the temperature of a selected thermocouple in the Shrike missile motor case reached 500°F.

Table 1 summarizes the results of tests conducted with washdown systems only.

Tests A-1R and A-6 show that when the system is used as designed (AFFF in both upwind and fire zone), the pool fires were readily controlled (24 and 30 seconds) and extinguished

(45 and 70 seconds) under 30 and 15 kt wind conditions respectively.

Table 1 - Effectiveness of Washdown Systems Combating Pool Fires

Test No.	Agent UZ	Agent FZ	Wind (kts)	Control Time (s)	Ext. Time (s)	Shrike Under Wing: Agent-on Temp. (°F)	Shrike Under Wing: Heat Rise (°F)	Shrike Under Wing: Cooling Rate (°F/s)	Comments
A-1R	A	A	30	24	45	573	81	5	
A-3R	W	A	30	No	No	510	8	9	85% extinguishment in 80 seconds
A-4	W	W	30	No	No	457	40	-	50% extinguishment in 60 seconds
A-2	-	A	30	No	No	461	170	10	80% extinguishment in 50 seconds
A-6	A	A	15	30	70	591	27	5	
A-7	W	A	15	45	No	—	—	-	No thermocouple data

NOTE: The following abbreviations will appear on data tables throughout the text:
UZ = Upwind Zone
FZ = Fire Zone
A = AFFF
W = Water
Ext. = Extinguishment

This result was consistent with previous test data [1,2]. The reduced effectiveness of employing AFFF in the fire zone only was demonstrated in Test A-2 where only 80% fire extinguishment was achieved in 50 seconds, as opposed to 90% control in 24 seconds and extinguishment in 45 seconds where the system was used as designed. Fire was readily extinguished on the downwind 2/3 of the deck but the fire continued to burn between the nozzles along the leading edge due to the lack of agent from the upwind zone (to fill these gaps). Tests A-3R and A-7, which simulated the NIMITZ conditions with water in the upwind zone and AFFF in the fire zone, achieved only minimal control, no extinguishment and little or no improvement over no upwind zone at all. The water from the upwind zone diluted the AFFF in the fire zone preventing extinguishment. Test A-4 was a test of water only in both zones. In this case, the fire was not extinguished. Only 50% fire control was obtained in 60 seconds.

In all of these tests cook-off was prevented except in A-2 where fire persisted in strips from the leading edge of the fire zone and continuously heated the wing-hung Shrike. This pattern of fire and extinguishment consistently occurred when there was no agent from the upwind zone. During Test

A-4, with water in both zones there was no cook-off, but only 50% of the fire was extinguished in 60 seconds, as compared to Test A-2 where 80% was extinguished in 50 seconds and there was cook-off. The reason for the cook-off in A-2 is significant and can only be attributed to the location of the remaining fire, however small, which in this case continuously heated the weapon. These tests emphasize the extreme importance of rapid and total fire extinguishment as the most effective, in fact the only effective, means of preventing cook-off of current weapons and the value of utilizing the upwind washdown zone whenever possible.

Cooling rates were low (5 to 10°F/second) because the ordnance which was suspended 5 ft above the deck was beyond the range of the flush deck nozzles and hence received mainly air-cooling and a small amount of wind-blown agent.

The impact of adding obstacles such as a debris pile or tires to the pool fire was also studied and recorded in Table 2.

Table 2 - Effectiveness of Washdown Systems Combating Pool Fires with Debris Pile

						Shrike Under Wing			Sidewinder in Debris Pile			Obstructions		
Test No.	Agent UZ	Agent FZ	Wind (kts)	Control Time (s)	Ext. Time (s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Debris Pile	Tires	Comments
A-30	A	A	30	40	No	474	32	3	428	267	None	Yes*	No	Pool fire ext. in 70 seconds. Hand line used to ext. debris pile.
A-52	W	A	30	No	No	658	65	4	424	194	3	Yes*	No	80% ext. in 60 seconds
A-39	A	A	30	24	No	677	77	4	—	—	—	No	Yes	Pool fire ext. in 35 seconds. Hand line to ext. tires.
A-40	W	A	30	80	No	839	100	3	—	—	—	No	Yes	Pool fire ext. in 110 seconds. Hand line to ext. tires.
A-54	W	A	30	No	No	410	456	12	754	551	None	Yes	Yes	F.d. washdown nozzles intentionally plugged. 80% ext. in 110-160 seconds.
A-53	A	-	30	No	No	667	75	4	416	950	None	Yes*	No	85% ext. in 50 seconds

*No running fuel in debris pile.

When AFFF was used in both zones, control was established in 24 and 40 seconds (Tests A-39 and A-30) but extinguishment was not obtained because the wind conditions and obstacles prevented the AFFF from completely covering the fire area. The effect of applying AFFF only from the upwind zone resulted in unsatisfactory performance (only 85% fire extinguishment in 50 seconds, Test A-53). Test A-40, A-52 and A-54 again showed reduced effectiveness when applying water from the upwind zone along with AFFF in the fire zone as control was not gained. As expected, fire continued to burn downwind of the obstacles. In all of these tests involving the debris pile with the Sidewinder missile (Tests A-30, A-52, A-53 and A-54), cook-off would have occurred (heat rise from 194°F to 950°F) due to the inability of the washdown system to extinguish fire within the debris pile with or without running fuel.

The heat rise in the Shrike missile motor case attached to the underside of the aircraft mock-up wing ranged from 32° to 100°F for all tests except A-54, where the heat rise was 456°F resulting in cook-off. Fire extinguishment in A-54 was impeded by the presence of both a debris pile and tires, and the plugging of 4 out of 11 washdown system nozzles in the leading edge of the fire zone. The combined obstacles simulated the conditions that existed during the NIMITZ fire. This fire was neither controlled nor extinguished. In washdown system tests, generated wind caused a low profile of the agent spray from the washdown nozzles. This resulted in very little cooling of the ordnance by direct impingement. The cooling rates ranged from 3 to 12°F/second, which is only slightly better than air cooling alone (approximately 4°F/second). The temperature recorded in the Sidewinder missile motor case in the debris pile shows the ineffectiveness of cooling inside the pile by the washdown system alone and therefore cook-off would have occurred. The key factor in limiting heat rise is obviously rapid and complete extinguishment of the fire.

These tests successfully duplicated most of the conditions reported from the NIMITZ fire and show the extreme importance of using the washdown systems as designed -- AFFF in both zones.

In summary, these tests demonstrated the washdown system when used alone is capable of extinguishing a pool fire in a matter of 45 seconds. When debris was added to the pool fire, control time was extended and extinguishment was not achieved. When water was used in the upwind zone with AFFF in the fire zone, extinguishment was not achieved as the water diluted the fire zone agent. Water in both zones was not particularly effective (50% extinguishment in 60 seconds) but nonetheless did provide some extinguishment.

6.4 Increased Flow Washdown Systems

In a further attempt to extinguish the running fuel fire in the debris pile, the flow rate in the AFFF washdown system was increased to 125 gpm by either increasing pressure or orifice size of the Grinnell Type SB standard flush deck nozzle. A specifically designed Bete spray nozzle, which flowed 250 gpm at 40 psi, was used for the highest flow tests.

Nozzle configurations and pressures used in this test series were:

1. Grinnell Type SB flush deck nozzle, 0.4375 in. orifice (30 gpm at 30 psi and 60 gpm at 120 psi)

2. Grinnell Type SB nozzle drilled to 0.50 in. orifice (60 gpm at 70 psi)

3. Grinnell Type SB nozzle drilled to 0.625 in. orifice (60 gpm at 30 psi and 90 gpm at 57 psi)

4. Grinnell Type SB nozzle drilled to 0.750 in. orifice (90 gpm at 30 psi and 125 gpm at 100 psi)

5. Bete 3 in. nozzle designed to flow 250 gpm at 40 psi with a 40 ft diameter pattern in zero wind

Six nozzles were installed upwind of and beside the debris pile as shown in Fig. 20. The debris pile had the unshielded side upwind. In all tests, there was a 60 second pre-burn followed by 60 seconds of agent application in a 30 kt wind.

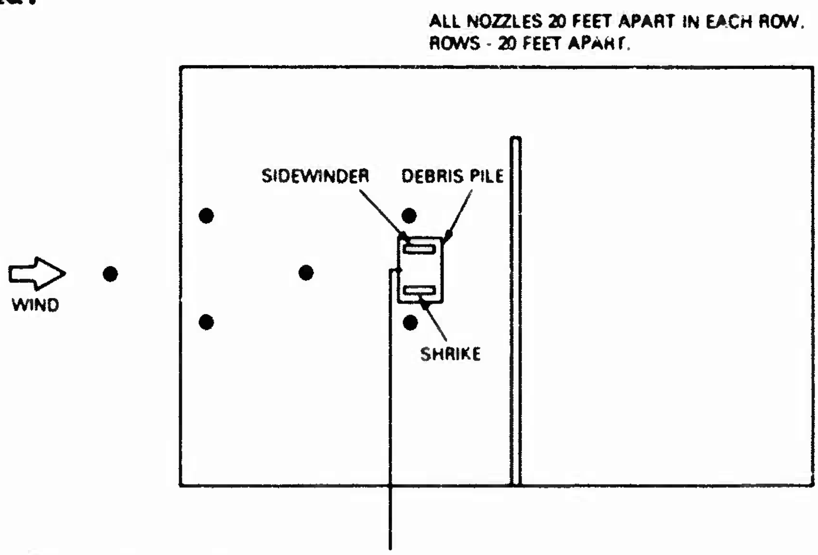


Fig. 20 - Increased flow washdown system six nozzle array

6.4.1 Debris Pile Fires

In tests against the full debris pile (Table 3), none of the increased flow systems extinguished the running fuel fire. At flows of 30, 60, and 90 gpm (Tests E-20, E-21, and E-17), substantial heat rise was evident (300 to 500°F) and cook-off would have occurred in each case. At flows of 125 and 250 gpm (Tests E-19 and E-22) the heat rise was high for 3 out of 4 pieces of ordnance (159 to 200°F, and cook-off would have occurred for all but Test E-22 Sidewinder.

Table 3 - Increased Flow Washdown System
Full Debris Pile

					Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Flow Per Nozzle (gpm)	Orifice Dia. and Nozzle Type	Nozzle Pressure (psi)	Ext. Time (s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
E-20	30	0.4375 "S"	30	No	670	465	None	763	527	None
E-21	60	0.4375 "S"	120	No	785	462	None	944	327	None
E-17	90	0.750 "S"	30	No	484	499	10	685	316	None
E-19	125	0.750 "S"	100	No	522	159	10	755	183	22
E-22	250	Bete	40	No	650	200	13	908	10	29

Since the full debris pile was not extinguished in any of these tests, the upwind wall of the debris pile was removed to provide more direct access to the fire (Table 4). Flows of 30 and 60 gpm (Test E-25 and E-26) did not extinguish the running fuel fire, and cook-off would have occurred in 3 out of 4 cases (the Test E-26 Sidewinder with a heat rise of only 6°F is the exception). At flows of 90, 125, and 250 gpm (Tests E-27, E-28, and E-29) the running fuel fire was extinguished in each case with lower heat rise (10 to 81°F) and cooling rates of 5 to 35°F/second. Ordnance cook-off would not have occurred under these test conditions.

Table 4 - Increased Flow Washdown System
Debris Pile Without Upwind Wall

					Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Flow Per Nozzle (gpm)	Orifice Dia. and Nozzle Type	Nozzle Pressure (psi)	Ext. Time (s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
E-25	30	0.4375 "S"	30	No	531	409	None	762	242	15
E-26	60	0.4375 "S"	120	No	587	249	None	662	6	23
E-27	90	0.750 "S"	30	45	669	81	14	626	10	35
E-28	125	0.750 "S"	100	30	724	90	7	407	36	28
E-29	250	Bete	40	45	736	76	5	679	30	35

Table 5 contains the one test run with 30 gpm nozzles against the running fuel fire with all debris pile walls removed (Test E-30). The fire was not extinguished, but ordnance cook-off was avoided, since heat rise was limited to 103°F.

Table 5 - Debris Pile With All Walls Removed -- Type "S" Nozzle

					Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Flow Per Nozzle (gpm)	Orifice Dia. and Nozzle Type	Nozzle Pressure (psi)	Ext. Time (s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
E-30	30	0.4375 "S"	30	No	756	103	3	663	39	10

A number of tests were conducted with varied debris pile configurations (Table 6). With the upwind wall removed the fire was not extinguished at flows of 30, 60 and 90 gpm per nozzle (Table 6, G-1 through G-5). Heat rise was less than 117°F in all cases except for the Sidewinder in Test G-1 and the Shrike in G-5. This was a result of small fires persisting in the area of the weapon. Cooling rate was good at 15 to 22°F/second in several cases, but was very low (2 to 3°F/seconds) in other situations.

Table 6 - Increased Flow Washdown Systems -- Varied Debris Pile Configuration

					Shrike in Debris Pile			Sidewinder in Debris Pile			
Test No.	Flow Per Nozzle (gpm)	Orifice Dia. and Nozzle Type	Nozzle Pressure (psi)	Ext. Time (s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Debris Pile Configuration
G-1	30	0.4375 "S"	30	No	872	0	15	735	200	No	No upwind wall
G-2	60	0.500 "S"	70	No	208	0	3	618	0	15	No upwind wall
G-3	60	0.625 "S"	30	No	254	117	2	603	57	22	No upwind wall
G-4	90	0.625 "S"	57	No	257	3	30	580	0	2	No upwind wall
G-5	90	0.625 "S"	57	No	200	211	3	763	27	15	No upwind wall
G-6	90	0.625 "S"	57	No	344	78	3	912	26	25	No upwind wall No loose debris
G-7	90	0.625 "S"	57	Yes	651	0	30	506	0	2	No upwind or downwind wall No loose debris
G-8	90	0.625 "S"	57	No	892	106	0	314	0	25	No upwind or downwind wall No loose debris

This inconsistency was probably the result of the variable, wind-blown flow pattern from the washdown system. Higher nozzle pressure (70 psi) in Test G-2 produced a higher pattern and provided better heat rise control and higher cooling rates than Test G-3 (at 30 psi) for the same 60 gpm flow rate. Removal of the loose debris in the bottom of the debris file (Test G-6) did not result in extinguishment of the debris pile. With the upwind and downwind walls removed, the 90 gpm flow did provide extinguishment in one test (G-7) but could not quite extinguish in a repeat (G-8). Heat rise was contained in both tests and one missile motor case cooled well in each test.

It is obvious from these data that the washdown system alone will not readily extinguish running fuel fire in a debris pile even at flows as high as 90 gpm per nozzle. Small fires that persist behind obstacles must be handled by other means, such as hand lines.

6.4.2 Pool Fires

These tests were conducted using the 10 nozzles in the upwind zone only, flowing at 30 gpm, 60 gpm and 90 gpm per nozzle with wind of 30 kts against a 4,000 sq ft JP-5 pool fire. Results are shown in Table 7.

Table 7 - Increased Flow AFFF Washdown Systems
Upwind Zone 10 Nozzles With Pool Fires

						Shrike Under Wing			Shrike Under Aft Wing		
Test No.	Flow per Nozzle (gpm)	Orifice Dia. and Nozzle Type	Nozzle Pressure (psi)	Control Time(s)	Ext. Time (s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
E-48	30	0.4375 "S"	30	30	None	822	38	11	721	217	4
E-50	60	0.4375 "S"	120	16	None	854	58	5	702	17	6
E-51	90	0.750 "S"	30	16	None	699	28	10	564	41	5

Instrumented weapons consisted of a Shrike under the forward wing and a Shrike under the aft wing of the aircraft mock-up.

The pool fire was controlled in 30 seconds with a 30 gpm flow rate per nozzle. Doubling the flow to 60 gpm reduced the control time by one-half to 16 seconds but no further

reduction occurred when flow was increased to 90 gpm per nozzle. Heat rise was minimal on both weapons with 60 and 90 gpm/nozzle but at 30 gpm/nozzle the ordnance on the aft wing had a 217°F heat rise which would have resulted in cook-off. Cooling rate in all cases was low at 5 to 11°F/second.

In the tests of increased flow washdown systems against a debris pile fire, several significant facts were confirmed. No flows up to 250 gpm/nozzle could extinguish a debris pile fire, nor did any flow from 30 to 125 gpm, and prevent cook-off. However, changing the configuration by removing the upwind wall did allow systems from 60 to 250 gpm to provide cooling and prevent cook-off. Most significant was the fact that above 60 gpm, no improvement was obtained. Against a pool fire, increasing the flow of the washdown systems to 60 gpm reduced the control time to one-half of that achieved with 30 gpm/nozzle. No further reduction was achieved with flows of 90 gpm/nozzle.

6.5 Hand Lines

During the NIMITZ tests, 1-1/2 in. hard hose on reels and 2-1/2 in. hose with MIL SPEC nozzles flowing either water or AFFF were tested individually or together against pool fires. The effectiveness of 1-1/2 in. and 2-1/2 in. hand lines in aggressive extinguishing attack was compared with an attack which alternatively attempted extinguishment and weapons cooling. The value of a 2-1/2 in. line in cooling weapons from a 50 ft stand-off position was determined as were the relative cooling abilities of AFFF and water.

All tests were run against a 4,000 sq ft, JP-5 pool fire in a 30 kt wind. The instrumented Shrike missile motor case was suspended beneath the forward aircraft mock-up wing.

Teams with a minimum of three fire fighters were used on the 2-1/2 in. hose and teams of two fire fighters were used on the 1-1/2 in. hose. In a 30 kt wind, the 2-1/2 in. hose teams had difficulty maintaining their footing and advancing on the fire. This difficulty was compounded by the presence of AFFF on the concrete test deck. This may not be as severe on a non-skid surface.

Table 8 summarizes the result for single hand line tests in fire extinguishment and alternate cooling and extinguishment.

Table 8 - Single Hand Line Against Pool Fires

Test No.	Hand Lines (Agent) 1-1/2 in.	Hand Lines (Agent) 2-1/2 in.	Control Time (s)	Ext. Time (s)	Strike Under Wing: Agent-on Temp. (°F)	Strike Under Wing: Heat Rise (°F)	Strike Under Wing: Cooling Rate (°F/s)	Comments
A-12R	A	—	27	42	620	28	3	Hand line dedicated to fire ext. only
A-8	—	A	27	50	526	18	5	Hand line dedicated to fire ext. only
A-13	A	—	49	56	619	9	13	Hand line alternating between ordnance cooling and fire ext.
A-14	—	A	42	50	530	36	13	Hand line alternating between ordnance cooling and fire ext.

The data for comparing 1-1/2 in. (Test A-12R) and 2-1/2 in. (Test A-8) AFFF hand lines dedicated to fire extinguishment does not show a clear superiority for either size line. Similar control times (27 seconds each), extinguishing times (42 and 50 seconds) and ordnance cooling rates of 3° and 5°F (air cooling only) were recorded. Under 30 kt winds the superior maneuverability of the 1-1/2 in. hand line compensated for the greater reach and flow rate of the 2-1/2 in. hose. Tests A-13 and A-14 examined alternately cooling ordnance and extinguishing fire with each AFFF line. Higher ordnance cooling rates (13°F/second each) were achieved in both tests, but control and extinguishment took longer. If only a single hand line is available, concentrating on extinguishment rather than attempting to alternate between extinguishment and weapons cooling results in more rapid control and extinguishment. The small gain in ordnance cooling which results from alternating between extinguishing and cooling is more than outweighed by the importance of aggressively extinguishing the fire. Cook-off would have been prevented in all of these tests since heat rise never exceeded 36°F. Table 9 summarizes the two hand line test results.

Table 9 - Two Hand Lines Against Pool Fires

Test No.	Hand lines (Agent) 1-1/2 in.	Hand lines (Agent) 2-1/2 in.	Control Time (s)	Ext. Time (s)	Shrike Under Wing Agent-on Temp. (°F)	Shrike Under Wing Heat Rise (°F)	Shrike Under Wing Cooling Rate (°F/s)	Comments
A-9R	A	A	13	19	472	50	3	Both hand lines dedicated to fire ext. only
A-37	—	1 W 1 A	30	44	642	6	4	Both hand lines dedicated to fire ext. only
A-15	A	W	26	47	550	38	15	Hand line aggressive attack mode 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling
A-24	A	A	18	33	535	46	25	Hand line aggressive attack mode 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling
A-16	A	W	39	66	496	30	36	Hand line 50 ft. stand-off 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling
A-18	A	A	30	53	530	11	20	Hand line 50 ft. stand-off 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling

Combined 1-1/2 in. and 2-1/2 in. AFFF hand lines dedicated to extinguishment dramatically lowered control time to 13 seconds and extinguishment time to 19 seconds (Test A-9R). Combining one AFFF 2-1/2 in. and one water 2-1/2 in. resulted in prolonged fire control and extinguishment time (Test A-37). Cook-off, however, would not have occurred in any of these tests.

Since it was a common practice in the Fleet to employ 2-1/2 in. water hand lines for ordnance cooling in conjunction with 1-1/2 in. AFFF hand lines dedicated to fire extinguishment, tests were conducted comparing this mode with AFFF in both hand lines in the aggressive attack technique, and then at 50 ft stand-off (Tests A-15, A-24, A-16 and A-18). Control and extinguishment times were clearly superior (as much as 50%) when the tactic was to aggressively attack and extinguish the fires whether or not water was used in the 2-1/2 in. hand line. However, hand lines using AFFF only were at least 30% more effective than the combined use of AFFF and water in extinguishing the fire. Weapons cooling by either water or AFFF is comparable. The higher cooling rates observed for the 2-1/2 in. water stream at a 50 ft stand-off were attributed to the operator's ability to direct and "fix" the stream on the weapon while standing rather than maneuvering the hose line (Tests A-15 and A-16).

A combination of 1-1/2 in. and 2-1/2 in. hand lines using AFFF against a pool fire was effective in both control and extinguishment with control in 13 seconds and extinguishment in 19 seconds. Using a single hand line to alternately cool weapons and extinguish the pool fire significantly extended control times, without providing an equivalent gain in ordnance cooling. When two hand lines were used, the 1-1/2 in. with AFFF extinguishing and the 2-1/2 in. with water or AFFF for weapons cooling, using AFFF in both reduced control and extinguishment by 30% without any degradation in cook-off prevention.

6.6 Washdown System and Hand Line Combinations

This series was conducted in order to compare the use of AFFF alone and in combination with water in both washdown zones and hand lines as employed during the NIMITZ fire. Partially due to equipment failure, the NIMITZ fire attack employed water in the upwind washdown zone and 2-1/2 in. hand lines, and AFFF in the washdown fire zone and 1-1/2 in. hand lines. Tests were conducted against pool fires and combined pool and debris pile fires. In some tests, tires were laid in the pool to provide additional obstruction to extinguishment. The initial tests were against a JP-5 pool fire only (Table 10).

Table 10 - Washdown System and Hand Line Combinations

Test No.	Wind (kts)	Washdown Agent UZ	Washdown Agent FZ	Hand Lines Agent 1-1/2 in.	Hand Lines Agent 2-1/2 in.	Control Time(s)	Ext. Time (s)	Shrike Under Wing Agent-on Temp. (°F)	Shrike Under Wing Heat Rise (°F)	Shrike Under Wing Cooling Rate (°F/s)	Comments
A-19	30	W	A	A	W	33	54	521	85	20	1-1/2 in. 50 ft. stand-off ext., 2-1/2 in. 50 ft. stand-off cooling
A-20	30	A	A	A	A	18	26	548	29	16	1-1/2 in. ext. and 2-1/2 in. cooling, aggressive attack
A-22	15	W	A	A	W	29	44	603	6	34	1-1/2 in. 50 ft. stand-off ext., 2-1/2 in. 50 ft. stand-off cooling
A-21	15	A	A	A	A	23	30	619	16	16	1-1/2 in. 50 ft. stand-off ext., 2-1/2 in. 50 ft. stand-off cooling

In Test A-19 where the water/AFFF washdown combination was employed along with hand lines held at the 50 ft stand-off position (NIMITZ fire scenario), the pool fire was controlled in 33 seconds and extinguished in 54 seconds. With all systems using AFFF and both hand lines in aggressive attack, the fire was controlled and extinguished in one-half the time. When these tests were repeated with 15 kts of wind, the use of AFFF in all systems reduced the control and extinguishment times by approximately one-third when compared to the water/AFFF combination. These tests indicate that the 30 kt wind aided in the dispersion of the AFFF. The effect of wind is less pronounced when comparing the same agent combinations, e.g., Tests A-20 and A-21, where control times varied from 18 to 23 seconds and extinguishment times from 26 to 30 seconds.

A comparison of water/AFFF combinations to all AFFF combinations and 50 ft stand-off tests (A-19, 20, 21 and 22), showed water higher in cooling in both 15 and 30 kt winds. Heat rise in all tests was minimal, ranging from 6 to 85°F, indicating that cook-off would not have occurred. The major differences were in control and extinguishment times. The water/AFFF combinations resulted in significantly longer times for both control and extinguishment. This, again, demonstrates that the gain in cooling which may result from the use of water, as opposed to AFFF, is more than outweighed by the importance of rapid control and extinguishment of the fire.

In pool fires with a debris pile both hand lines quickly knocked down the pool fire. Then the 1-1/2 in. line concentrated on the debris pile while the 2-1/2 in. cooled the ordnance. Raising the hand line over the debris pile wall and rotating the nozzle distributed the agent effectively and extinguished the running fuel fire within the pile. The flexibility of the 1-1/2 in. hand line makes it clearly more practical than the 2-1/2 in. against a debris pile of this type. Table 11 contains the data for pool debris pile fires.

With the debris pile added to the pool fire in 30 kts of wind, times for control and extinguishment of the pool fire were extended slightly. This was consistent with earlier tests of the washdown systems only with a debris pile in a pool fire (A-53 and A-54 in Table 1).

Table 11 - Washdown System and Hand Line Combinations Pool and Debris Pile Fires

Test No.	Wind (kts)	Washdown Agent UZ	Washdown Agent FZ	Hand Lines Agent 1-1/2 in.	Hand Lines Agent 2-1/2 in.	Control Time(s)	Pool Ext. Time (s)	D.P. Ext. Time (s)	Shrike Under Wing Agent-on Temp. (°F)	Shrike Under Wing Heat Rise (°F)	Shrike Under Wing Cooling Rate (°F/s)	Sidewinder in Debris Pile Agent-on Temp. (°F)	Sidewinder in Debris Pile Heat Rise (°F)	Sidewinder in Debris Pile Cooling Rate (°F/s)	Comments
A-27R1	30	W	A	A	W	40	52	122	515	33	26	509	464	4	Hand line aggressive attack mode, 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling
A-25R	30	A	A	A	A	22	30	50	486	18	11	645	448	9	Hand line aggressive attack mode, 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling
A-26	15	A	A	A	A	39	41	72	766	154	3	585	363	11	Hand line aggressive attack mode, 1-1/2 in. fire ext., 2-1/2 in. ordnance cooling 3-5 kt. crosswind

The 1-1/2 in. hand line with AFFF was used in all tests for debris pile extinguishment. The 2-1/2 in. hand line was used primarily for weapons cooling; however, it was apparent that when AFFF was used it aided in initial fire suppression prior to weapons cooling. Water in the 2-1/2 in. hand line provided little or no fire suppression assistance and, in fact, spread the fire in some tests. This resulted in an extension of time for the 1-1/2 in. hand line to go over the wall of the debris pile and begin extinguishment.

Debris pile extinguishment was significantly longer when water instead of AFFF was used in the upwind zone of the washdown system; by as much as 30 to 40 seconds. In these cases, fire was seen to persist in the bottom of the debris pile even after the running fuel fire was extinguished. This accounts for the very long debris pile extinguishing time (122 seconds) observed in Test A-27RI. AFFF in the upwind zone contributes to fire extinguishment in the bottom of the debris pile as seen in Tests A-53 and A-54.

In all of these tests, weapon cook-off was avoided on the wing-hung Shrike with minimal heat rise. The Sidewinder in the debris pile fire cooked-off in all cases with high heat rise (332 to 464°F).

In Test A-26 when the wind was reduced to 15 kts, control and extinguishment times were longer than in Test A-24R. Time to begin debris pile attack with the 1-1/2 in. hand line was extended because an ambient 5 kt crosswind

forced the 1-1/2 in. hand line back during the attack. In this test both weapons cooked-off with heat rise of 154°F in the Shrike and 363°F in the Sidewinder.

The last two tests in this series compared the impact of "correct" activation of AFFF washdown zones and hand lines (A-55) on fire extinguishment vs. the "delayed" (2-min. pre-burn) NIMITZ scenario utilizing water/AFFF combinations (A-56). Hand lines approached the fire into the wind in both tests. The data for these tests are presented in Table 12.

Table 12 - Washdown System and Hand Line Combinations
Pool and Debris Pile Fires, Debris (Tires) on Deck

Test No.	Wind (kts)	Washdown Agent UZ	Washdown Agent FZ	Hand Lines Agent 1-1/2 in.	Hand Lines Agent 2-1/2 in.	Control Time(s)	Pool Ext. Time (s)	D.P. Ext. Time (s)	Shrike Under Wing: Agent-on Temp. (°F)	Shrike Under Wing: Heat Rise (°F)	Shrike Under Wing: Cooling Rate (°F/s)	Sidewinder in Debris Pile: Agent-on Temp. (°F)	Sidewinder in Debris Pile: Heat Rise (°F)	Sidewinder in Debris Pile: Cooling Rate (°F/s)	Comments
A-55	30	A	A	A	A	40	60	100	426	74	15	158	627	9	1-1/2 in. alt. ext.; 2-1/2 in. cool; h.l. into wind; 36 s preburn
A-56	30	W	A	A	W	195	235	420	1026	0	14	1193	199	4	1-1/2 in. ext.; 2-1/2 in. alt. ext. and cool; h.l. into wind; 4 plugged f.d. nozzles

For Test A-55, 15 aircraft tires were piled in front of the debris pile in the pool fire in the forward section of the fire zone. After a 36 second pre-burn both AFFF washdown zones were activated. Thirty seconds later the 1-1/2 in. and 2-1/2 in. AFFF approached the fire from the starboard, downwind side. Control of the pool fire was achieved in 40 seconds. The hand lines were able to slowly advance into the fire area and both initially concentrated on pool fire and tire pile extinguishment which occurred at 60 seconds. At 56 seconds the 1-1/2 in. line was directed to the debris pile fire which was extinguished at 100 seconds. Heat rise on the wing ordnance was low and cooling rate was fair. Ordnance in the debris pile had a substantial heat rise of 627°F and cook-off would have occurred.

Test A-56 included an additional complication of four plugged nozzles in the fire zone. The pre-burn time was extended to 120 seconds before activation of the water/AFFF

washdown zones. Water/AFFF hand lines were delayed an additional 120 seconds and then approached the fire from the starboard downwind side. At the time, the fire was only 60% extinguished by the washdown system. Control was achieved in 195 seconds only with the aid of hand lines. The 1-1/2 in. AFFF hand line concentrated on deck fire extinguishment while the 2-1/2 in. water hand line cooled the underwing Shrike. At 235 seconds, the deck fire was out, except for the tire pile and the 1-1/2 in. hand line attacked the debris pile. At 420 seconds, the tires and debris pile were extinguished. Cook-off obviously had already taken place; however, the washdown system immediately stopped heat rise on the wing-hung weapon. The Sidewinder in the debris pile continued to heat rapidly.

It should be obvious that quick response to a fire situation with all systems utilizing AFFF in a conflagration such as the NIMITZ fire is imperative. However, in every test run with washdown systems and hand lines, weapons in the debris pile would have cooked-off. The tests strongly reinforce the urgent need to improve weapons cook-off characteristics.

6.7 Single and Dual Monitors

Aggressive hand line attack is effective but may endanger fire fighters. An alternative tactic was tested using portable 500 gpm and 1,000 gpm Akron monitors supplied by existing 2-1/2 in. hose lines to permit safer, remote extinguishing of running fuel debris pile fires. Also, dual monitors at various distances from the debris pile were studied. Tests were conducted with streams at various angles to the wind against the shielded and unshielded side of the debris pile, using the monitors singly and in pairs. Table 13 shows the test results.

After the NIMITZ tests, fires were given a 60 second pre-burn and agent was applied for 60 seconds. No attempt was made to estimate control or extinguishment times shorter than 60 seconds. A single instrumented missile motor case (Sidewinder) was located in the debris pile in tests labeled A through C. For tests labeled D and later (beginning with Systematic Tests Phase II, March 1983) two weapons (1 Shrike and 1 Sidewinder) were located in the debris pile.

The initial test, E-37, of a single 500 gpm monitor was made downwind against the unshielded side of the debris pile from a distance of 50 ft. The fire was extinguished. Heat rise was 125°F on the Shrike and 121°F on the Sidewinder, neither of which would have caused cook-off. Cooling rate was good at 20° and 27°F/second.

Table 13 - Single Portable Monitors Against Debris Pile

Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Shrike in Debris Pile Agent-on Temp. (°F)	Shrike in Debris Pile Heat Rise (°F)	Shrike in Debris Pile Cooling Rate (°F/s)	Sidewinder in Debris Pile Agent-on Temp. (°F)	Sidewinder in Debris Pile Heat Rise (°F)	Sidewinder in Debris Pile Cooling Rate (°F/s)	Comments
E-37	30	500	50	Yes	207	125	20	633	121	21	Akron Master TJ nozzle unshielded side with the wind
D-17	30	500	30	Yes	617	261	15	665	14	25	1-1/4 in. straight tip nozzle, crosswind
D-18	30	500	45	Yes	—	—	—	—	—	—	1-1/4 in. straight tip nozzle, crosswind
E-42	30	500	45	Yes	280	171	15	440	154	40	Akron Master TJ nozzle 1-1/4 in. straight, tip nozzle, crosswind
A-47	10	1000	100	No	—	—	—	500	180	8	Akron Master TJ nozzle with the wind shielded side
A-48a	10	1000	40	No	—	—	—	504	298	5	Akron Master TJ nozzle crosswind 30 degree fog, 90 seconds
A-48b	10	1000	40	No	—	—	—	905	75	10	Akron Master TJ nozzle 60 seconds crosswind straight stream

Test D-17 was a 500 gpm monitor stream in a crosswind directed into the side of the debris pile from a range of 30 ft. Fire fighting was for 60 seconds and the fire was extinguished. Heat rise was 261°F on the Shrike and 14°F on the Sidewinder which would have resulted in cook-off of the Shrike only. Cooling was good at 15°F/second and 25°F/second on the Shrike and Sidewinder respectively. In Test D-18 the monitor was positioned at an angle of 60° into the wind at a distance of 45 ft from the debris pile and the fire was extinguished. Thermocouple data could not be taken because excessive moisture in the junction box shorted out the thermocouples.

Test E-42 is a repeat of Test D-18 using the Akron Master Turbo Jet (TJ) nozzle. The monitor was carried in and positioned at 45 ft from the debris pile and at an angle of 60° into the wind. Fire fighting was for 60 seconds and the fire was extinguished. Heat rise was 171°F on the Shrike and 154°F on the Sidewinder, again resulting in cook-off of both. Cooling was good at 15°F/second on the Shrike and excellent at 40°F/second on the Sidewinder. Heat rise after

agent-on was a function of location of the nozzle with respect to each weapon. For example, in D-17, the Shrike was shielded from the stream by the near wall and heat rise was 261°F, while the Sidewinder was hit directly and heat rise was limited to 14°F. Of the six weapons exposed in three tests, three would have cooked-off even though the fires were extinguished in less than 120 seconds after fire ignition. The high cooling rates indicate that significant amounts of agent did reach the ordnance during fire fighting. The increased range, when the stream is directed into the wind compared to crosswind and differences in reach with various nozzles (Tests E-42 and D-17), was confirmed in other tests.

Three tests of single 1,000 gpm portable monitors were run in 10 kt ambient wind. In Test A-47 against the shielded side of the debris pile from a distance of 100 ft, the fire was not extinguished. Heat rise on the Sidewinder was 180°F and cooling 8°F/second.

In the crosswind test, A-48, the stream was directed through the triangular side opening from a distance of 40 ft. First, a 30° fog setting was used for 90 seconds and the fire was not extinguished. The heat rise on the Sidewinder was high (298°F) and would have resulted in cook-off. Test A-48B is a continuation of Test A-48A where the fire was allowed to build back up and the monitor was set on straight stream. Heat rise was held to 75°F which would have prevented cook-off. The fire was not extinguished but was controlled. Cooling rate for the fog setting was 5°F/second but with straight stream was 10°F/second. Even a 10 kt crosswind prevented the fog stream from reaching the debris pile with sufficient agent to contain the heat rise and provide cooling. Table 14 gives the results of monitors tested in pairs against the debris pile fire.

Table 14 - Dual Monitors Against Debris Pile

					Sidewinder in Debris Pile			
Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Comments
A-50	0	500/1000	40/50	Yes	500	146	12	side delivery against ends of debris pile
B-6	0	1000/1000	95/110	Yes	781	68	20	unshielded side
C-7	0	1000/1000	110/150	Yes	896	122	14	unshielded side
B-7	30	1000/1000	95/110	No	1054	38	18	unshielded side

In side delivery using a 500 gpm monitor at 40 ft and a 1,000 gpm monitor at 50 ft (Test A-50), the fire was extinguished with 45 seconds of agent application. Heat rise was 146°F with a cooling rate of 12°F/second. Due to location of the weapon on the starboard side of the debris pile, the 1,000 gpm monitor on the port side was the only monitor placing agent directly on the ordnance.

In Tests B-6 and B-7, two 1,000 gpm monitors were located 95 and 110 ft from the unshielded side and 55 ft to each side of the center line of the debris pile. In Test B-6 with zero wind, the fire was extinguished after 55 seconds of agent application. Heat rise was minimal (68°F) and cooling good at 20°F/seconds. Test B-7 was a duplicate of Test B-6 except in 30 kts of wind. The wind prevented the full stream from reaching the debris pile resulting in no extinguishment. Sufficient agent did enter the debris pile to keep the heat rise to 38°F and provide 18°F/second cooling.

The final test, C-7, was in zero wind with two 1,000 gpm monitors against the unshielded side of the debris pile from distances of 110 to 150 ft. The monitors were located similarly to Tests B-6 and B-7 and 60 ft from the center line of the debris pile. The fire was extinguished with heat rise limited to 122°F. Cooling was good at 14°F/second. The limiting range for extinguishing debris pile fires from the unshielded side with dual monitors was not identified in these tests but obviously is beyond 150 ft.

The effect of wind on Monitor streams is obvious from Test B-7 where even a 30° angle crosswind substantially reduced the range and prevented extinguishment.

6.8 Fixed Monitors

6.8.1 Monitors in Zero Wind

Installing high flow fixed monitors on aircraft carriers has been discussed for several years. Agent supply for such a system has been a major obstacle. After the NIMITZ incident, it was decided to further test these systems with flows up to 12,000 gpm to determine performance while a concurrent cost and feasibility study was conducted by NAVSEA and Norfolk Navy Shipyard [9].

The monitors would be installed in various locations and would be remotely controlled. Crosswind and into the wind range, the ability to reach over the 15-25 ft heights encountered with parked aircraft, potential damage to equipment and the danger to personnel were major concerns in location and flow rate selection.

The primary purpose of the fixed monitor tests was to determine their ability to extinguish debris pile fires from the shielded and unshielded sides. Would a few 8,000 - 12,000 gpm, several 4,000 - 8,000 gpm or many 1,000 - 4,000 gpm monitors be best? The locations of monitors during these tests with respect to the debris pile are shown in Fig. 21.

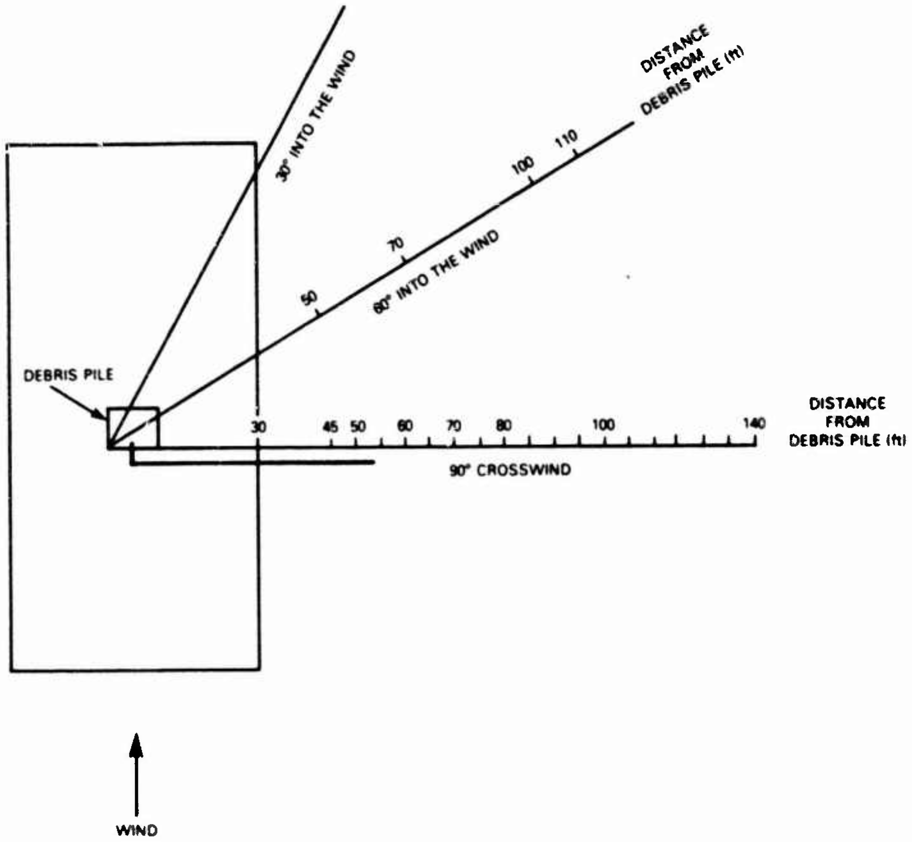


Fig. 21 - Monitor test locations

Fire tests of 250 to 4,000 gpm monitors against the unshielded side of the debris pile in zero wind are shown in Table 15.

During attacks on the unshielded side with no generated wind against the running fuel debris pile fire, the fire was extinguished by streams with flow rates from 250 gpm at 55 ft to 4,000 gpm at 325 ft. However, cook-off would have occurred in Tests C-2 and B-9 since heat rises of 231° and 171°F were obtained. This can be explained by the fact that the ordnance continued to heat for as much as 30 seconds after agent application began. This was due to the low flow rates (250 and 500 gpm) with little agent reaching the area

of the weapon and delayed extinguishment of fire under the weapon. Flows of 1,000 gpm and 2,000 gpm, each from 95 ft, gave immediate heat rise control (Tests B-5 and B-4 respectively). Test E-16 with 4,000 gpm from 325 ft held heat rise to 26°F in the Sidewinder and 56°F in the Shrike.

Table 15 - Monitors Against Unshielded Side of Debris Pile

					Sidewinder in Debris Pile			Shrike in Debris Pile		
Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
C-2	0	250	55	Yes	429	231	14	—	—	—
B-9	0	500	70	Yes	753	171	14	—	—	—
B-5	0	1000	95	Yes	[illegible]	6	6	—	—	—
B-4	0	2000	95	Yes	557	1	5	—	—	—
E-16	0	4000	325	Yes	632	26	8	487	56	40

The result of tests of 1,000, 5,000 and 12,000 gpm streams against the shielded side of the debris pile are shown in Table 16. During attacks on the shielded side of the debris pile in no wind, none of the monitors extinguished the fire. Test A-47, flowing 1,000 gpm from 100 ft, showed a heat rise of 180°F, and would have cooked-off the ordnance. Test B-1, flowing 5,000 gpm from 245 ft, showed a heat rise of 175°F and would have cooked-off. Contrary to some predictions, Test C-4, flowing 12,000 gpm from 350 ft, did not smother and extinguish the fire, although the debris pile was completely enveloped. Heat rise was controlled to 36°F.

Table 16 - Monitors Against Shielded Side of Debris Pile

					Sidewinder in Debris Pile		
Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
A-47	0	1000	100	No	500	180	8
B-1	0	5000	245	No	626	175	—
C-4	0	12000	350	No	688	36	9

These tests confirmed earlier tests and showed the futility of attempting to extinguish the fire from the shielded side. Only with the massive application of 12,000 gpm was heat rise controlled and cook-off prevented; however, the fire was still not extinguished after 60 seconds.

6.3.2 Monitors in Crosswind

These tests were conducted in order to establish the maximum distance at which streams of various flow rates could estinguish the debris pile fire in a 30 kt crosswind. Nozzles were generally straight stream nozzles operated at a nominal 100 psi. Test data are shown in Table 17.

Table 17 - Monitor Stream in Crosswind, Debris Pile Fire

					Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
D-15	30	100	30	No	740	75	0	—	—	—
D-16	30	250	30	No	—	—	—	—	—	—
D-17	30	500	30	Yes	617	261	25	665	14	15
C-11	30	1000	50	Yes	—	—	—	—	27	40
D-2	30	1000	60	No	989	494	0	1026	257	0
D-8	30	2000	80	Yes	479	31	52	484	23	29
D-7	30	2000	90	No	—	—	—	707	161	26
D-5	30	3000	100	Yes	483	70	15	302	152	12
D-6	30	3000	110	No	341	307	70	506	173	12
D-25	30	4000	140	No	—	—	—	—	—	—

The first test at each flow rate was conducted at a distance established during the no-fire stream reach tests which are discussed later. In most of the tests, the nozzle was then moved closer to or further from the debris pile until the maximum extinguishing distance was determined. Distances were all measured from the far wall of the debris pile, 12 ft further from the nozzle than the near wall.

The crosswind attack was made with the unshielded opening downwind. The monitors were positioned at various distances perpendicular to the wind direction as they would be used in shipboard side delivery systems. The streams were directed into the triangular opening between the top of the block wall and the slanted roof. This opening is approximat ly 9 ft long and 3 ft high at the downwind side.

Neither 100 gpm (Test D-15) nor 250 gpm (Test D-16) streams could extinguish the fire at a distance of 30 ft from the far wall of the debris pile (18 ft from the near wall). It was estimated that the 250 gpm stream would have extinguished the fire at 20 ft, but it was not tested due to the impracticality of such a close approach in these tests.

The fire was first extinguished at 30 ft (Test D-17) with a 500 gpm monitor with a straight stream nozzle. A 1,000 gpm stream extinguished the fire at 50 ft (Test C-11), but did not extinguish at a distance of 60 ft (Test D-2). At the 60 ft range the heat rise in both weapons could have resulted in cook-off and, in fact, was extremely high, indicating that the fire was neither controlled nor extinguished near the weapons. Tests D-7 and D-8 established the maximum effective fire fighting range of the 2,000 gpm monitor at 80 ft. Heat rise in both weapons in Test D-8 was minimal (31° and 23°F) and cooling excellent. At 100 ft (Test D-5), the fire was extinguished with a 3,000 gpm stream but the same stream did not extinguish at 110 ft (Test D-6). It was clear that the 4,000 gpm stream would be effective at a distance between 110 and 130 ft, since this monitor was not effective at 140 ft (Test D-25). At this point, further testing was deemed unwarranted because of the limited width of the generated wind.

6.8.3 60° Angle Attack

In non-fire tests analyzing monitor stream reach, it was evident that the monitor stream would reach further at a 60° angle to the wind than directly crosswind. Table 18 summarizes the results of 60° angle attack tests on the debris pile. The discussion that follows compares these results with those presented for crosswind effective reach in Table 17. In these tests the debris pile had the unshielded side open downwind, which allowed the monitor stream more area to attack than was available in the crosswind situation.

Table 18 - Monitor in 30 kt Wind, 60° Angle Attack, Debris Pile Fire

					Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
E-3	30	250	40	Yes	572	212	10	691	252	20
D-18	30	500	45	Yes	592	—	—	—	—	—
D-11	30	1000	60	Yes	621	31	3	293	24	4
D-10	30	1000	70	No	485	188	15	681	60	10
D-13	30	2000	110	Yes	719	24	12	715	168	50
D-14	30	3000	150	Yes	352	249	6	271	239	11

The effective range of a 500 gpm monitor (Test D-18) increased from 30 ft in crosswind as shown in Table 17 to 45 ft at a 60° angle. In Test D-11, a 1,000 gpm monitor's range increased from 50 to 60 ft and the fire was extinguished with very low heat rise on the ordnance. Cooling, also, was very low at only 3 and 4°F/second. The 2,000 gpm monitor in Test D-13 extinguished the fire at 110 ft compared to only 80 ft crosswind. Heat rise was 24°F on one weapon but 160°F on the other. The increase in effective range of the 3,000 gpm monitor at a 60° angle to the wind (Test D-14) was from 100 ft in crosswind to 150 ft. Heat rise was 249 and 239°F while cooling was low at 6 and 11°F/second. Cook-off would have occurred with both weapons in Test E-3, with the Shrike in Test D-13, and with both weapons in Test D-14. As discussed previously in the crosswind analysis of this phenomena, the same reasoning for cook-off applies here.

6.8.4 30° Angle Attack

Table 19 summarizes the results of 30° angle into the wind tests and the debris pile.

Table 19 - Monitor in 30 kt Wind, 30° Angle Attack, Debris Pile Fires

					Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
E-12	30	2000	95	Yes	567	79	15	801	129	40
E-4	30	2000	110	No	—	—	—	665	51	20

The 2,000 gpm monitor was tested to determine if any increase in range could be achieved when operating at a 30° angle into the wind. In crosswind tests (D-7 and D-8), the maximum effective range was determined to be 80 ft. In Test E-12 the fire was extinguished at 95 ft with low heat rise. At 110 ft (Test E-4) the fire was not extinguished. The minimum effective range was increased from 80 ft crosswind to 95 ft at 30° into the wind but was still not as effective in controlling heat rise as the 110 ft range obtained at 60° into the wind.

Table 20 presents the results of a test conducted with a monitor directed into the wind.

Table 20 - Monitor into a 30 kt Wind

Test No.	Flow (gpm)	Range (ft)	Ext.
D-26	1000	100	Yes

There are two major factors influencing the increase in effective extinguishing reach of the stream directed into the wind (Test D-26 extinguished at 100 ft) over that of the stream directed 60° into the wind (Test D-11, Table 18, extinguished at only 60 ft). In these tests, the stream into the wind was somewhat protected from the wind by the debris piles, however, greater reach into the wind was always observed in non-fire reach tests which results from "lift" and lesser exposure to wind of the majority of the stream.

6.8.5 Variable Height Monitors

These tests were designed to determine the effect of height on the maximum and minimum effective ranges of a 6,000 gpm monitor in 30 kt crosswind. An 8 in. Stang monitor flowing AFFF in a side delivery mode was used against the steel debris pile (Fig. 11) with a running fuel fire. The monitor was mounted on a platform which was adjusted to heights of 15, 20, 25, and 30 ft.

The steel debris pile was used so that it could be easily moved as required in these tests. The use of the steel debris pile caused very rapid weapons heating and much higher weapons temperatures at the end of the 60 second pre-burn than usual in the "standard" debris pile. However, this did not affect the validity of the thermocouple data. The results of these tests are shown in Table 21.

Table 21 - 6,000 gpm Variable Height Monitor, 30 kt Crosswind

				Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Nozzle Height (ft)	Distance to D.P. (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
F-2	30	150	No	876	39	20	1333	15	40
F-6	30	25	Yes	649	75	17	1056	54	15
F-3	30	90	Yes	846	0	30	1286	12	18
F-4	30	50	Yes	748	127	25	1146	35	15
F-5	30	25	No	598	63	12	711	25	30
F-8	25	150	No	553	89	12	1270	23	10
F-9	25	25	No	576	101	35	1059	44	9
F-10	20	150	No	461	104	12	1230	55	14
F-11	20	25	No	671	25	60	1138	49	27
F-13	15	150	No	765	98	30	1022	89	6
F-12	15	25	Yes	869	0	40	1005	22	14

The first tests were conducted at the 30 ft crosswind height against the steel debris pile at distances varying from 25 to 150 ft. The initial test, F-2, conducted at 150 ft from the debris pile failed to extinguish the fire but heat rise was low (39°F and 15°F) and cooling rates were high. This was the result of large quantities of agent entering the debris pile. Small fires persisted in the bottom of the pile that were not extinguished at a monitor distance of 150 ft regardless of monitor elevation (F-8, F-10 and F-13). The monitor in Test F-6 at 125 ft did extinguish the fire with low heat rise (75°F and 54°F) and good cooling rates (17°F and 15°F/second). Visual observation indicated that the fire could most likely be extinguished at a 140 ft distance.

In tests with the monitor at 25 ft from the debris pile, the fire was not extinguished at heights above 15 ft because the roof of the debris pile deflected the majority of the agent and shielded the upper portion of the running fuel fire (Tests F-5, F-9 and F-11) from the agent. However, the heat rise and cooling rates in these tests demonstrate that sufficient agent did enter the pile to extinguish low level fire around the weapons and provide cooling although the difficult, high level running fuel fire was not extinguished.

In Test F-13 with the monitor at a height of 15 ft, the fire was extinguished with minimal heat rise (0°F and 22°F) on each weapon. In this case the monitor had direct access into the debris pile. Table 22 summarizes the results of tests conducted to establish extinguishing range when the monitor was directed 60° into the wind rather than crosswind.

Table 22 - 6,000 gpm Variable Height Monitor, 60° Into the Wind

				Shrike in Debris Pile			Sidewinder in Debris Pile		
Test No.	Nozzle Height (ft)	Distance to D.P. (ft)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
F-16	30	140	Yes	539	109	18	824	132	14
F-17	30	45	Yes	611	4	55	886	96	30
F-14	15	180	No	913	275	None	1005	352	None
F-15	15	140	Yes	662	190	13	958	50	6

The 60° angle tests began at 140 ft range and 30 ft elevation (Test F-16). The fire was extinguished with low heat rise and good cooling. Another test (F-14) was

unsuccessful at 180 ft and was the only test in this series to result in cook-off of both the Shrike and Sidewinder. The high heat rise (275°F and 352°F) and no cooling was a clear indication that the stream did not reach the debris pile. Test F-15 also at 140 ft but at 15 ft elevation extinguished the debris pile, however, it resulted in cook-off of the Shrike since it was located on the port side of the debris pile and shielded from direct application of agent. The data in this test and Test F-16 shows that 140 ft is the maximum effective range of the 6,000 gpm monitor in the 15 to 30 ft height range.

The 30 ft elevation did not have any noticeable effect upon maximum range of the 6,000 gpm monitor, but, as anticipated, it had a strong effect upon minimum range. It is important to note that even though the fire was not extinguished at 20, 25 and 30 ft elevations and 25 ft range, cook-off was avoided and the weapon was cooled.

6.8.6 Erectable Monitor

These tests were conducted with a 1,000 gpm monitor atop a 30 ft high erectable tower. The monitor was controllable from the base of the tower in all directions. The purpose of the test was to determine if a monitor mounted high enough to direct a stream over aircraft tail assemblies could extinguish debris pile fires directly crosswind and 50 ft from the base of the tower (50 ft is the maximum crosswind range of the 1,000 gpm monitor).

Table 23 shows the results of these tests in 30 kt crosswind and no wind conditions. In the no wind test (D-22), the monitor readily extinguished the fire in the debris pile. In a 30 kt wind, the fire was extinguished in one case and not in the next because of operator technique where the stream was deflected (bounced) off of the top of the block sidewall. Wind conditions made it difficult to place sufficient quantities of AFFF on the fire from this height and range even though there was open area available in the side of the debris pile at this height and range. Weapons temperature data was not recorded during these tests due to equipment failure.

Table 23 - Erectable Monitor

Test No.	Wind (kts)	Flow (gpm)	Range (ft)	Agent Application Time(s)	Ext.
D-22	0	1000	50	139	Yes
D-23	30	1000	50	132	No
D-24	30	1000	50	127	Yes

6.9 P-16 Vehicle Tests

The P-16 Aircraft Carrier Flight Deck Crash Rescue Vehicle, Fig. 22, is the initial response fire fighting unit for carrier flight deck fires. This vehicle is approximately 18 ft long, 5 ft wide and 3 ft high. It is equipped with a 350 gpm pump and a 400 gallon premixed water/AFFF solution tank. The fire fighting equipment before modification consisted of a 100 gpm driver-operated turret, a 60 gpm AFFF hand line with 50 ft of 1 in. hose, and a PKP/AFFF twin agent unit hand line. A nursing connection was located on the starboard side to allow resupply of AFFF from a 2-1/2 in. hand line.

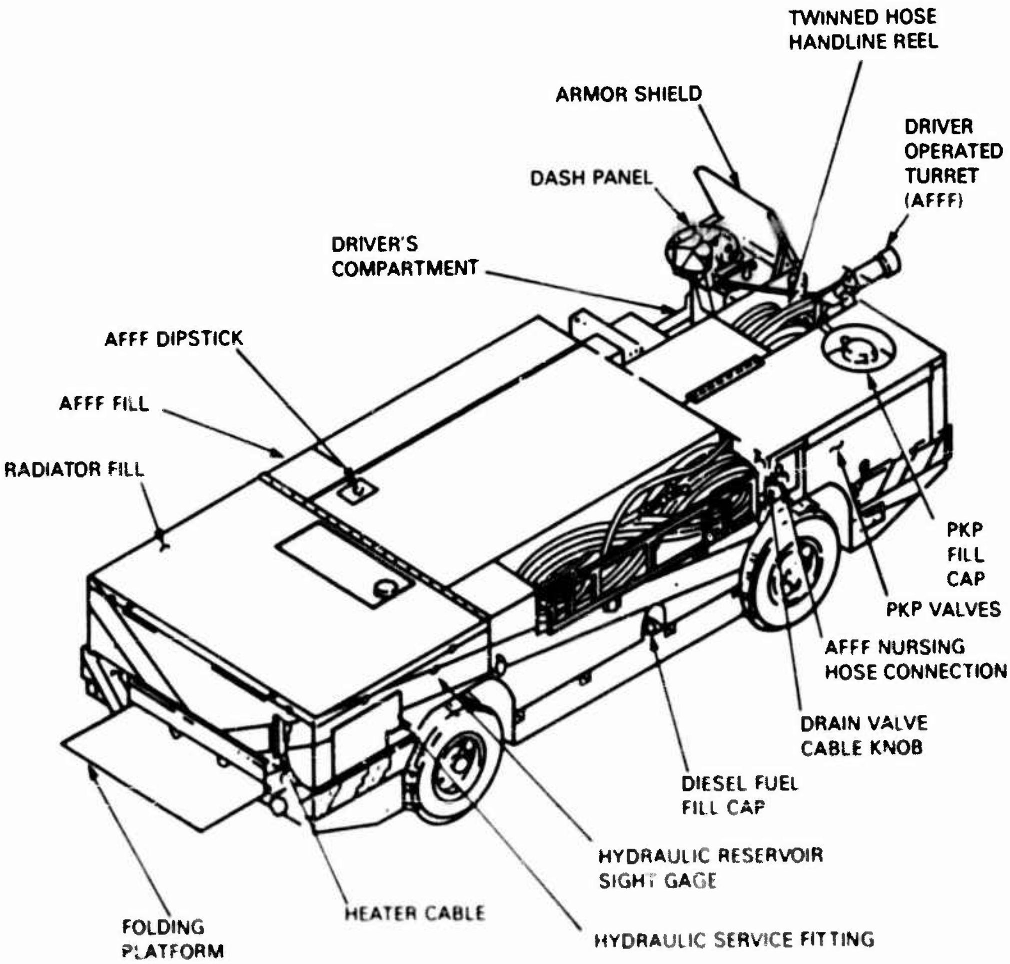


Fig. 22 - A/S 32 P-16 Fire fighting vehicle

The purpose of these tests was to evaluate potential improvements for the P-16 which would improve the fire fighting capability and not result in major modifications. For example, increased turret flow, comparison of PKP and Halon 1211 in the twin agent unit, a lockable turret, a protective shield for the driver, and relocation of the nursing connection to the aft port side. Prior to any modification, the P-16 was tested against debris pile fires under no wind and 30 kt wind conditions. These tests determined that this specific turret (Elkhart SFL) flowed 100 gpm at 80 psi nozzle pressure and the hand line flowed 60 gpm at 60 psi. With changes in the piping layout, post modification tests resulted in 240 gpm at 90 psi with a MIL SPEC 2-1/2 in. nozzle and 162 gpm at 185 psi with the original 1-1/2 in. nozzle on the turret. The hand line flow remained at 60 gpm at 60 psi. The PKP in the twin agent unit was converted to Halon 1211. The flow rate of the Halon 1211 was 5 lb/second compared to 4 lb/second of PKP. The turret was modified by adding vertical and horizontal locking devices. Tests were run against the debris pile (full or with the front wall removed) and most often with the unshielded side upwind in a 30 kt wind.

Comparative tests (E-33 and E-32) where PKP and Halon 1211 only were used against a debris pile fire showed that neither could extinguish the fire at the 5 lb/second flow rate. Heat rise was 253°F and 266°F with Halon and 522°F and 752°F with PKP. No cooling was evident with either agent, and cook-off would have occurred in both tests. Table 24 summarizes the results of the PKP and Halon 1211 Tests.

Table 24 - P-16 PKP and Halon 1211 Tests

			Shrike in Debris Pile			Sidewinder in Debris Pile			
Test No.	Wind (kts)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent/D.P. Modification
E-33	30	No	522	522	None	214	752	0	PKP - 5 lbs/s
E-32	30	No	754	253	None	885	266	0	Halon 1211 - 5 lbs/s
H-1	30	No	986	244	None	333	63	0	Halon 1211 - 5 lbs/s front wall removed from d.p.
E-35	30	Yes	577	317	5	572	346	5	Halon 1211 - 10 lbs/s two trucks 5 lbs/s each

As seen in Table 24, no significant improvement in heat rise or cooling rates resulted when Halon was used, even with the front wall removed. Thirty knot winds did make it difficult to utilize Halon 1211 to its maximum capability. For Test E-35, the Halon 1211 application rate was doubled by using two hand lines and the fire was extinguished, but heat rise was 317°F and 346°F respectively for the Shrike and Sidewinder. Subsequently, cooling for each weapon was only 5°F/second, and cook-off would have occurred. Table 25 summarizes the results of the twinned agent units.

Table 25 - P-16 Twinned Agent Units, Debris Pile

			Shrike in Debris Pile			Sidewinder in Debris Pile			
Test No.	Wind (kts)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Comments
E-38	30	Yes	556	495	5	188	246	13	PKP/AFFF
E-39	30	Yes	575	385	12	140	—	—	Halon 1211/AFFF; Sidewinder temperature too low for cooling to be recorded
H-7	30	Yes	790	160	8	452	38	10	Halon 1211/AFFF; front wall removed from debris pile

When PKP and Halon 1211 were individually twinned with AFFF, the fire was extinguished. Test E-38 showed a heat rise of 495°F on the Shrike and 246°F on the Sidewinder. This test used twinned agents of PKP/AFFF, which also provided cooling of only 5° and 13°F/second. As a result, cook-off would have occurred in both weapons. Test E-39 showed a heat rise of 385°F on the Shrike, with cooling of 12°F/second using twinned Halon 1211/AFFF. Again, cook-off would have occurred. Test H-7, with the front wall removed yielded a Shrike heat rise of 160°F with a cooling rate of 8°F/second. On the Sidewinder, heat rise was 33°F and cooling 10°F/second. Shrike cook-off would have occurred in both Test E-39 and H-7, however, the fire was extinguished.

Observers noted that manhandling the twin agent unit (TAU) over the debris pile wall, in Tests E-38 and E-39, was an extremely difficult task. The TAU requires a minimum of two fire fighters to deploy and control, with a third fire fighter needed to pull hose when greater than 20 ft is used.

When the front wall was removed as in Test H-7, fire fighters had easy access to the fire and the fire was subsequently extinguished. Heat rise was still high because of the time required in deploying the twinned agent unit (approximately 30 seconds).

Increased flow and nozzle pressure improved the fire extinguishing capability of the P-16, especially with the front wall of the debris pile removed. The results of these tests are shown in Table 26.

Table 26 - P-16 AFFF Turret and Hand Line, Debris Pile

					Shrike in Debris Pile			Sidewinder in Debris Pile			
Test No.	Wind (kts)	Turret Flow (gpm)	Hand Line Flow (gpm)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)	Comments
E-6	0	100	40	Yes	768	82	20	383	4	—	
H-5	30	175	60	Yes	612	64	40	453	106	40	front wall removed from d.p.
H-4	30	240	60	Yes	703	71	30	357	24	20	front wall removed from d.p.

Tests H-5 and H-4 in Table 26 show that cook-off on both weapons was avoided. The Sidewinder in Test H-5 had a heat rise of 106°F, and a high cooling rate of 40°F/second.

P-16 turret only tests against the standard debris pile, summarized in Table 27, kept the Sidewinder below cook-off heat rises in Tests E-40 and H-9, but the Shrike experienced heat rises of 22°F and 260°F respectively, thus causing cook-off. In Test H-9, with the turret discharging agent for 170 seconds, extinguishment could not be achieved until the hand line discharging an additional 60 gpm was brought in. The hand line and turret extinguished the fire 35 seconds after the hand line was deployed.

Table 27 - P-16 Turret Only

Test No.	Wind (kts)	Flow (gpm)	Ext.	Shrike in Debris Pile Agent-on Temp. (°F)	Shrike in Debris Pile Heat Rise (°F)	Shrike in Debris Pile Cooling Rate (°F/s)	Sidewinder in Debris Pile Agent-on Temp. (°F)	Sidewinder in Debris Pile Heat Rise (°F)	Sidewinder in Debris Pile Cooling Rate (°F/s)	Comments
E-5	0	100	No	649	139	8	369	14	0	
E-36	30	125	Yes	450	442	4	600	65	17	
E-40	30	250	Yes	603	222	15	492	71	15	2-1/2 in. MIL SPEC nozzle in hose control device
H-9	30	175	No	602	260	—	468	69	8	Crosswind attack

Four tests using the P-16 turret only were conducted against the debris pile in 0 and 30 kt winds. In addition, a 250 gpm hand line in a hose control device was mounted on the P-16 to compare a higher flow turret to the 100 gpm produced by the original P-16 turret.

All tests were made from the upwind position (with the wind) against the unshielded side of the debris pile with the exception of Test H-9. This was a crosswind test with the debris pile oriented so the shielded side was upwind.

In Test E-5 with zero wind and 100 gpm flow, the fire was nearly extinguished from a distance of 25 ft. Fire fighting continued until the P-16 agent supply tank was exhausted (approx. 4 min). Heat rise was 139°F and 14°F respectively for the Shrike and Sidewinder. Both ordnance would have avoided cook-off. Tests E-36 and E-40 were run in a 30 kt wind with the P-16 located 50 ft from the debris pile. The P-16 was nursed in both cases. In both tests the fire was extinguished. Heat rise of the Shrike was high (442°F) in E-36 at 125 gpm flow. Doubling the flow (E-40) resulted in only one-half the heat rise. The Shrike would have cooked-off in both tests. The Sidewinder heat rise was low in all cases, probably due to agent impingement directly on the weapon. In Test H-9, the modified P-16 with turret flow of 175 gpm failed to extinguish the fire in a 30 kt crosswind even when the vehicle was moved as close as possible (10 ft) to the debris pile.

6.10 Robot Tests

Previous tests showed that a 500 gpm monitor stream could extinguish a debris pile fire and contain heat rise. Therefore, two commercial robot units capable of flow rates of 500 gpm or more were identified and one unit was tested. The specific purpose of these tests was to demonstrate the feasibility of the robot concept rather than any particular robot.

One manufacturer, Rural/Metro Fire Protection, Inc. of Scottsdale, Arizona, agreed to furnish their unit, including an operator for testing. This unit is known as the "Snail" and appears in Figs. 23 and 24. The Snail measures 48 in. long, 36 in. high and 26 in. wide. It is a battery-powered, tracked vehicle remotely controlled via an umbilical cord. Its 500 gpm monitor is supplied by a 3 in. hose. The nozzle can be rotated through 360°, elevated to 45° and depressed to 10°. The vehicle can turn within its own length, has a forward and reverse gear and a top speed of 3-4 mph. Higher speeds could be achieved by changing the gear ratio.

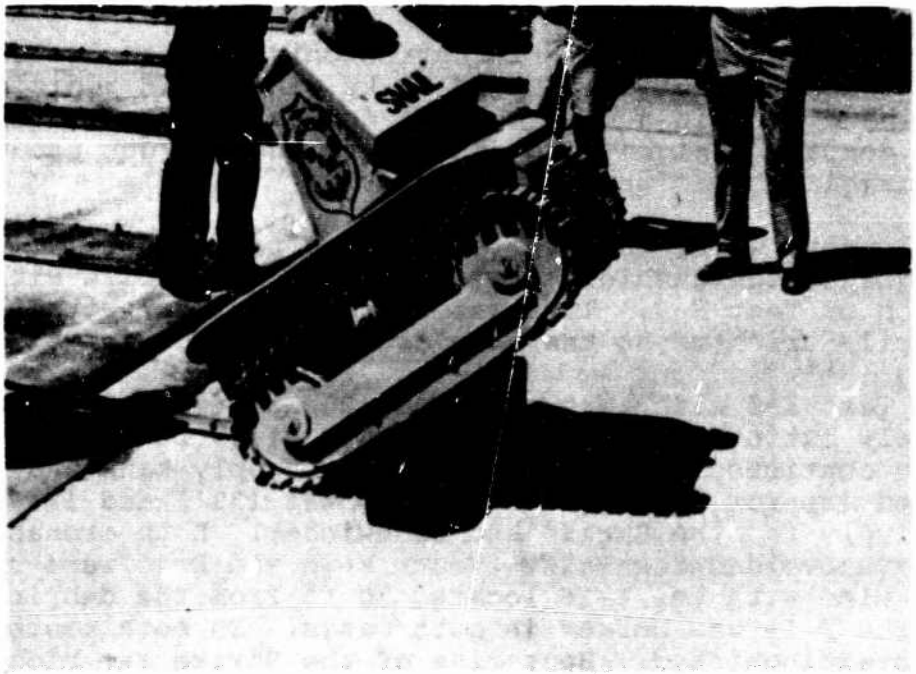


Fig. 23 - Remotely controlled robot successfully climbing an obstacle

Fig. 24 - Robot extinguishing a debris pile fire

Table 28 summarizes the results of the five fire tests conducted with the Snail during the Concepts and Refinement Series. These tests proved that:

1. it could pull 50 ft of charged 3 in. line without impeding its operational capability;

2. it is maneuverable enough to operate in a crash environment;

3. although some tests had cook-off level heat rise, the Snail could be operated successfully against a debris pile fire. (Tests were conducted in 30 kt wind conditions with attacks at 60° angle upwind and with the wind. The fire was extinguished in all tests but G-13 where the approach was poor due to operator error.)

The Snail demonstrated a stability problem due to its narrow width design which allows it to go through 30 in. doorways, however, it was maneuverable and demonstrated the feasibility of a remotely controlled robot fire fighter.

Table 28 - Robot Fire Fighter Tests

Test No.	Wind (kts)	Ext.	Shrike in Debris Pile: Agent-on Temp. (°F)	Shrike in Debris Pile: Heat Rise (°F)	Shrike in Debris Pile: Cooling Rate (°F/s)	Sidewinder in Debris Pile: Agent-on Temp. (°F)	Sidewinder in Debris Pile: Heat Rise (°F)	Sidewinder in Debris Pile: Cooling Rate (°F/s)	Comments
G-10	0	Yes	—	—	—	631	43	35	
G-11	30	Yes	294	533	3	502	10	35	With wind, unshielded side
G-12	30	Yes	188	93	4	1146	4	—	With wind, unshielded side
G-13	30	No	907	212	8	1200	111	10	60 degrees into the wind
G-14	30	Yes	801	208	—	1140	78	—	60 degrees into the wind

6.11 Additional Tests

6.11.1 200 Square Foot Deck Fire

The purpose of this test series was to determine if blanketing ordnance lying on the deck with AFFF would insulate and accelerate cook-off and if any cooling advantage could be gained using water rather than AFFF. Table 29 summarizes the results of four tests conducted with an instrumented Shrike missile motor case on the deck in a 200 sq ft JP-5 pool fire.

Table 29 - 200 sq ft Pool Fires
20 Knot Wind

Test No.	2-1/2 in. Hand Line Agent	Agent Application Time (s)	Ext. Time (s)	Shrike on Deck: Agent-on Temp. (°F)	Shrike on Deck: Heat Rise (°F/)	Shrike on Deck: Cooling Rate (°F/s)
A-31	W	130	No	514	10	31
A-32	A	130	9	559	0	38
A-33	A	90	8	573	0	42
A-34	W	90	No	543	41	42

Attack was by 2-1/2 in. hand line comparing water and AFFF at the same flow rate and application times (Tests A-31 through A-34). Heat rise was minimal. AFFF did not insulate even though the ordnance was completely covered and remained covered for at least 2 min. In all tests, the cooling rates were high and the weapon reached ambient temperature and remained there within 60 seconds of agent on. The cooling effects of AFFF and water were comparable with no insulating effect from AFFF. Significantly, the fires were extinguished with AFFF and, while suppressed, were not extinguished with water.

6.11.2 JP-4

Situations arise where aircraft return to a carrier with JP-4 fuel after a refueling stop at an Air Force land base or in flight refueling from an Air Force Tanker. This test series was designed to determine the effectiveness of various agents and tactics in fighting a JP-4 fueled debris pile fire. The data are presented in Table 30. In Test A-41, AFFF was used unsuccessfully first in a 1-1/2 in. hand line for 56 seconds and then a 2-1/2 in. hand line for 52 seconds.

Table 30 - JP-4 Running Fuel Debris Pile Fire Tests

Test No.	Wind (kts)	Agent	Hand Line	Agent Application Time (s)	Ext.	Sidewinder in Debris Pile: Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
A-41(a)	15	A	1-1/2 in.	56	No	406	222	8
A-41(b)	15	A	2-1/2 in.	52	No	267	18	—
A-41(c)	15	PKP/A	TAU	51	No	430	64	20
A-42	15	A	1-1/2 in. 2-1/2 in.	75	No	453	230	17

Also a twin agent unit using PKP and AFFF was unsuccessful for a 51 second application time. Test A-42 was a 1-1/2 in. and 2-1/2 in. combined hand line attack using AFFF at a total flow rate of 300 gpm for 75 seconds but, again the fire was not extinguished.

Obviously, JP-4 when compared to JP-5 is far more difficult to extinguish in a running fuel fire than JP-5.

6.11.3 1,000 gpm Trainable In-Deck Nozzle

This nozzle was designed for possible use in the center section of the flight decks of aircraft carriers where wind severely limits the reach of nozzles located at the deck edge. The trainable nozzle was designed to swing up from a recess in the deck when the system was activated. It was postulated that the higher (1,000 gpm) flow rate would provide coverage at vulnerable center deck points. The stream was directed approximately 10° above the deck. Test data is shown in Table 31.

Table 31 - MPR 1,000 gpm In-Deck Nozzle, Debris Pile

				Sidewinder in Debris Pile		
Test No.	Flow (gpm)	Wind (kts)	Ext.	Agent-on Temp. (°F)	Heat Rise (°F)	Cooling Rate (°F/s)
D-28	1000	0	Yes	140	244	--
D-27	1000	30	No	165	17	--

In Test D-28 the debris pile was extinguished from the side under 0 wind conditions at a distance of 40 ft. However, in Test D-27, the side attack in 30 kt of wind and 40 ft from the debris pile, the fire was not extinguished because insufficient agent entered the pile. Due to the limited reach in wind, further testing at this time was discontinued.

6.11.4 Protective Shields

Since it has been established that flight deck fire fighting personnel can be exposed to ordnance cook-off within 60 seconds after fire ignition, the need for personnel protection was addressed [10]. Test data is recorded in the Consolidated Data Sheet in the Appendix (Tests E-10 and G-15). A portable shield was designed to permit personnel to advance to less than 50 ft of the fire when using hand lines. The shield proved heavy and difficult to maneuver. It also exposed additional personnel to the same hazards while positioning the shield.

Later a wheeled shield with a 2-1/2 in. hose line was tested. The time and personnel required to move and tie-down this device made its use also of questionable value. Test data is recorded in the Consolidated Data Sheet in the Appendix (Tests E-10 and G-15). Due to the difficulty of use, limited protection provided, high cost and space requirements, work on shields was discontinued.

6.11.5 Hose Control Devices

The need to provide a method of continuously attacking a crash fire with hand lines within the 50 ft cut-off range without unnecessary hazard to personnel was the reason for testing hose control devices.

The Elkhart hose control device (Fig. 25) that was designed and used for structural fire fighting is a tripod type device that is attached to the hose by two clamps. The hose stream can then be directed by moving the hose and then tightening the clamps. It had to be tied down to padeyes by straps to prevent movement when the line was charged. The fire fighter can then retreat to a location safe from ordnance.

The Akron device (Fig. 26) was designed to attach directly to the end of the hose and the nozzle to attach to the other end. The water then flows through the device which is a ball joint and can be rotated in all directions and clamped down when the stream was properly directed. The device has a hook on the bottom which hooks into the cross bar on a padeye.

Both units are available in 1-1/2 in. and 2-1/2 in. sizes.

Ten tests were conducted with hose control devices against the running fuel fire in the debris pile using both 1-1/2 in. and 2-1/2 in. hand lines at a 50 ft stand-off distance, singly and in combinations, in 0 and 30 kt winds. The results of these tests are shown in Table 32.

The most important criterion was the ability of fire fighters to deploy the hand line, tie it down and withdraw rapidly. During the tests, it was found that the device could be set up within 30 seconds.

Fire fighters indicated that the hose control device made the deployment of a charged 2-1/2 in. hand line much

Fig. 25 - Elkhart hose control device

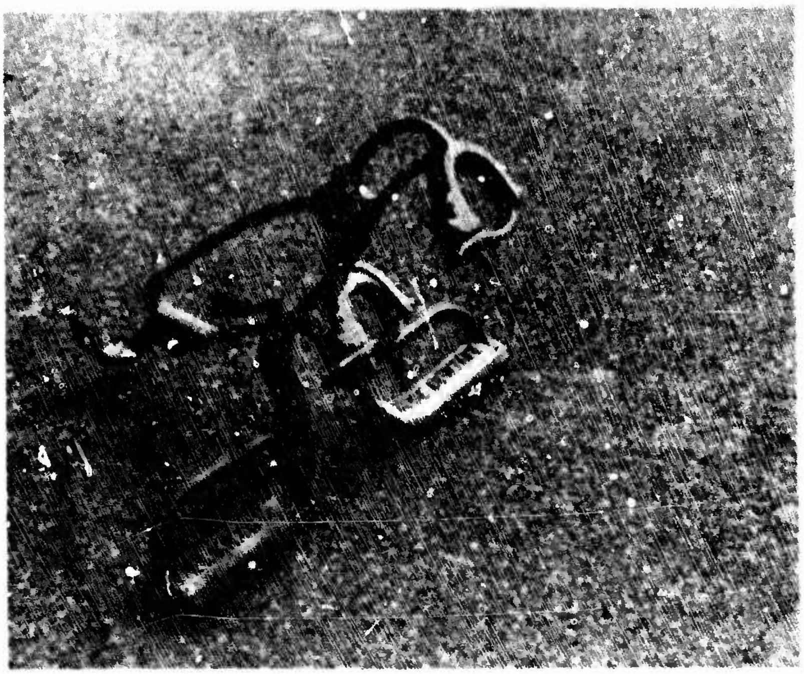


Fig. 26 - Akron hose control device

easier. Extinguishment of a debris pile fire using the hose control device from a 50 ft stand-off position required more time than an aggressive attack, but the improvement in personnel safety may offset this liability. Only in Test E-7, when the fire fighters first used this device, did they fail to extinguish the fire.

Table 32 - Hose Control Devices Against Debris Pile Fires

Test No.	Wind (kts)	Ext.	Shrike in Debris Pile Agent-on Temp. (°F)	Shrike in Debris Pile Heat Rise (°F)	Shrike in Debris Pile Cooling Rate (°F/s)	Sidewinder in Debris Pile Agent-on Temp. (°F)	Sidewinder in Debris Pile Heat Rise (°F)	Sidewinder in Debris Pile Cooling Rate (°F/s)
SINGLE 2-1/2 in. HAND LINE								
E-7	0	No	570	165	6	514	0	10
E-8	0	Yes	556	103	10	389	0	12
G-17	0	Yes	765	69	8	991	60	12
G-16	30	Yes	798	109	7	1092	125	12
SINGLE 1-1/2 in. HAND LINE								
G-18	30	Yes	643	160	8	765	102	13
DUAL 2-1/2 in. HAND LINES								
E-9	0	Yes	579	71	10	688	0	30
E-23	30	Yes	556	153	20	765	95	28
E-24	30	Yes	755	91	30	956	110	15
E-43	30	Yes	487	98	16	809	61	21
1-1/2 in. and 2-1/2 in. HAND LINES								
G-19	30	Yes	925	195	6	1082	120	15

6.12 Stream Reach

6.12.1 Stream Reach Tests

Wind is a part of the environment of an aircraft carrier deck and may range from 0 to 30 kts depending upon the situation. Generally, wind across a carrier deck can be expected to be 15 to 30 kts during landing operations which is a critical time for aircraft operations and catastrophic fires. In the course of testing various equipment used in carrier deck fire fighting, it became clear that the reach of a fire fighting stream in wind conditions can vary

significantly. As a part of the study of monitors for aircraft fire fighting, it became necessary to measure the effective range of the various size monitors in a 30 kt crosswind.

There was little in the literature to provide guidance on the effective reach of hose streams in wind and virtually no data on large streams. Freeman [11] noted that winds above 8 mph had serious effects on streams. The U.S. Coast Guard provides that 75% of the reach of monitor streams tested in still air will be considered effective reach when installed on oil platforms and weather decks of ships [12]. Monitors with flow rates up to 12,000 gpm were being considered for use on the flight deck. The initial tests were conducted to establish the approximate distance of a monitor from a debris pile prior to beginning actual fire testing that would determine maximum extinguishment range. These distances were measured accurately as evidenced by the fire tests which show that initial location of the monitor was within 10 ft of the maximum extinguishment range. In addition to crosswind reach, measurements were taken at 30° and 60° angles into the wind and directly into the wind at horizontal elevation. Where possible, elevations of 10° and 30° (approximate maximum reach in still air) were measured also. The nomenclature used to describe stream reach tests is shown in Fig. 27.

5 angles of nozzle with respect to wind:

1. With wind (downwind)
2. Crosswind
3. 30° into wind
4. 60° into wind
5. Into wind

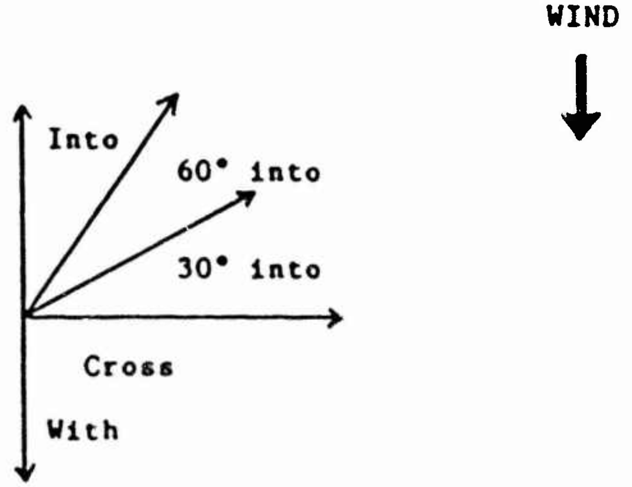


Fig. 27 - Stream reach nomenclature

A total of ten different flow rates were tested. These were approximately:

250 gpm	2,500 gpm
500 gpm	3,000 gpm
750 gpm	4,000 gpm
1,000 gpm	6,000 gpm
2,000 gpm	12,000 gpm

For flows from 1,500 to 4,000 gpm Stang straight bore nozzles and stacked tip nozzles were used. At flows from 500 to 1,500 gpm stacked tips were used. For the 250 gpm flow a 2-1/2 in. MIL SPEC nozzle was used. At 5,000, 6,000 and 12,000 gpm a Stang nozzle designed to provide straight stream and fog was used. In all tests a Stang 3, 4, 8 or 10 in. monitor was utilized.

Nozzle pressure was measured by a gauge located in the barrel of the monitor. In some low flow tests (500 to 2,500 gpm) an ultrasonic flow meter was used to confirm flow rates calculated from pressure readings.

All tests were conducted with water which compares favorably with AFFF in stream reach characteristics. One factor that limited the scope of tests was the inability to provide a 30 kt wall of wind of sufficient size to allow crosswind and into the wind tests at flow rates above 6000 gpm.

6.12.2 <u>Stream Reach Test Results</u>

An important consideration for shipboard use had to be the effect of increased or decreased nozzle pressure upon stream reach. High pressures (200 psi) are not available on most flight decks. Fig. 28 shows the stream reach of the 1-3/4 in. stacked tip with pressures ranging from 25 psi to 200 psi. The increase in flow and reach is shown as the pressure increases.

Increase in pressure results in an increase in stream reach until a critical point is reached. Every nozzle can be expected to have this point and for the 1-3/4 in. stacked tip this is 150 psi. This limiting nozzle pressure is a function of nozzle and monitor design.

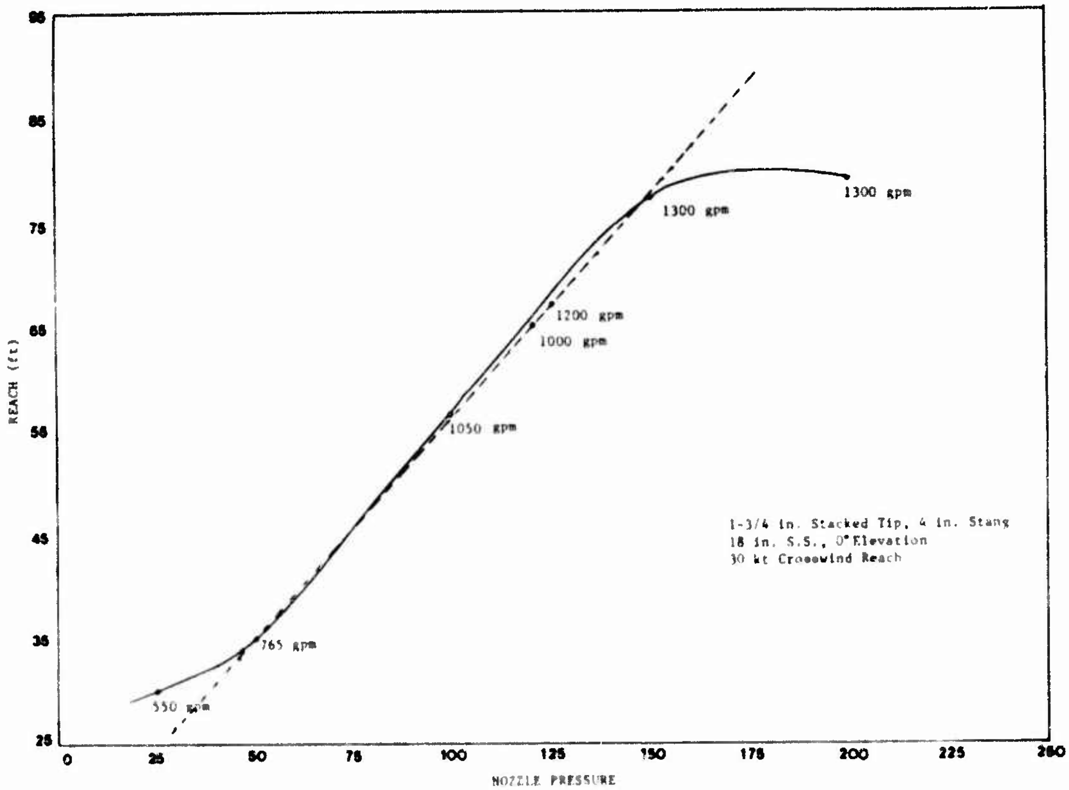


Fig. 28 - Reach increase vs. nozzle pressure increase

Most streams demonstrated an increase in reach as the stream was angled into the wind. This is most likely the result of the decrease in the area of the stream that is being acted upon by the wind. The stream will generally increase over crosswind reach approximately 10% at 30° into the wind and 30% at 60° into the wind, while reach directly into the wind can be as much as 100% greater than the crosswind reach. A plot of a typical stream reach for variou angles to the wind is shown in Fig 29. While other data supports these general increases in reach, the exact amount of increase is difficult to predict. The type of nozzle and thus the type of stream have a significant impact on this data.

The elevation of the monitor was increased from 0° to 10° which is the maximum angle that would stay within the wind wall at flows of 2,000 to 2,500 gpm. This small increase in elevation had a significant impact upon stream reach. This ranged from 30% in crosswind conditions to 50% in into-the-wind conditions. The overall increase of a 10° elevation into the wind over a horizontal (0°) elevation crosswind is almost 300%. At 30° the overall increase in the same situation is approximately 50% and at 60° angle to the wind is approximately 100%. Maximum stream reach in no wind is accepted to be 32° elevation. This was confirmed during the tests.

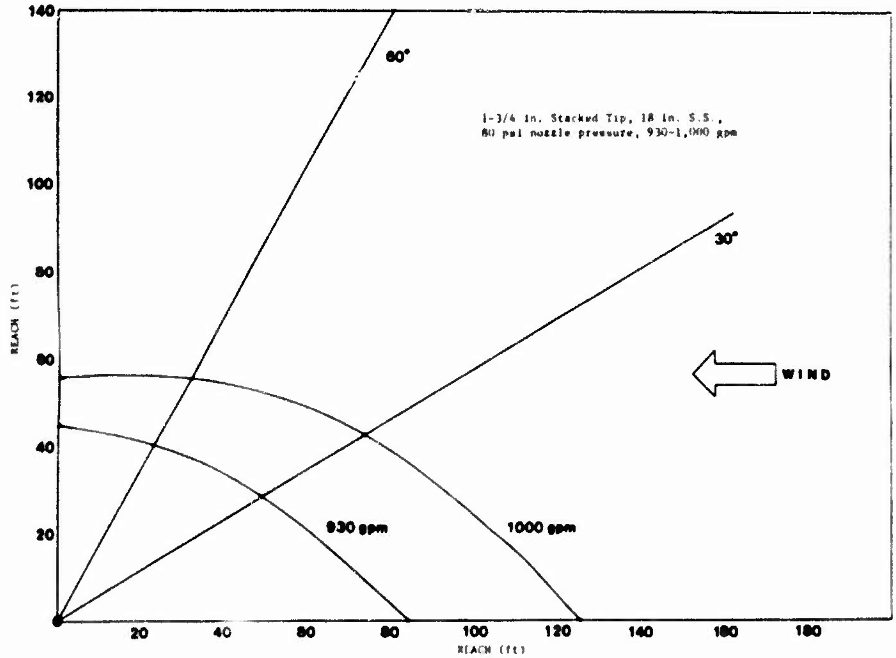


Fig. 29 - 1-3/4 in. stacked tip reach
(at varied angles to the wind)

The flow rate was increased from 500 to 2,300 gpm using a 10° elevation and maintaining a nozzle pressure of 80 psi. At the lower flows of 400 to 1,000 gpm, little effect is seen upon stream reach, while at 1,200 to 1,500 gpm a significant improvement is realized. From 1,000 to 1,600 gpm an increase of range of almost 100% occurs. However, from 1,600 to 2,300 gpm, no further increase in reach was achieved (see Fig. 30).

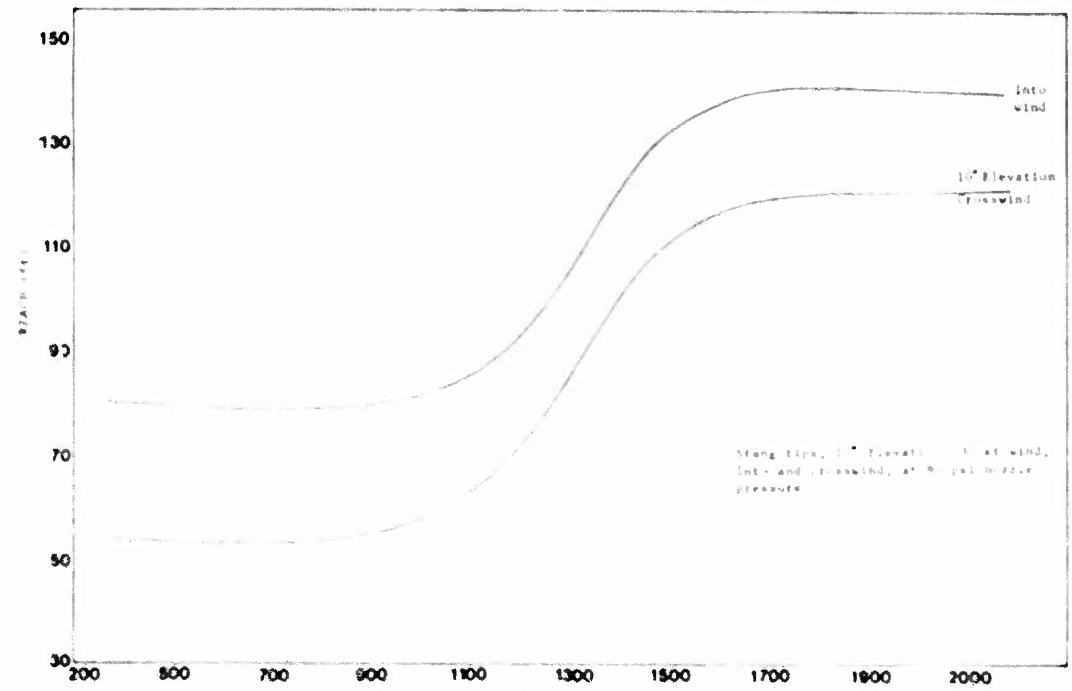


Fig. 30 - Stang tips, 10° elevation, 30 kt wind, into and crosswind, at 80 psi nozzle pressure

All of these tests were at 10° elevation and the increases were evident in both into-the-wind situations and crosswind.

It is clear that the more coherent the stream, the further it will reach in wind conditions. A straight tip backed up with a stream straightner provided the greatest reach. This was especially true in crosswind conditions, but did not seem to be as significant in into-the-wind tests.

6.12.3 Effect of Stream Angle to Wind on Fire Extinguishment

The greatest significance of stream reach is the distance at which a fire can be controlled and extinguished. A series of tests were conducted under 30 kt wind conditions against the debris pile running fuel fire. The data for these tests are in Appendix B. Figure 31 depicts the results of these tests. The effective reach of a stream in wind was defined as that distance where the majority of the stream reached, but in debris pile fire tests the effective extinguishment range was normally less. This was attributed to the difficulty of extinguishing a running fuel fire and the geometry of the debris pile. Thus, while a 1,000 gpm stream can "effectively" reach 60 ft, it can extinguish the debris pile fire from only 50 ft. A 2,000 gpm stream can reach 115 ft with a large quantity of agent, however the range to extinguish the debris pile fire was only 80 ft.

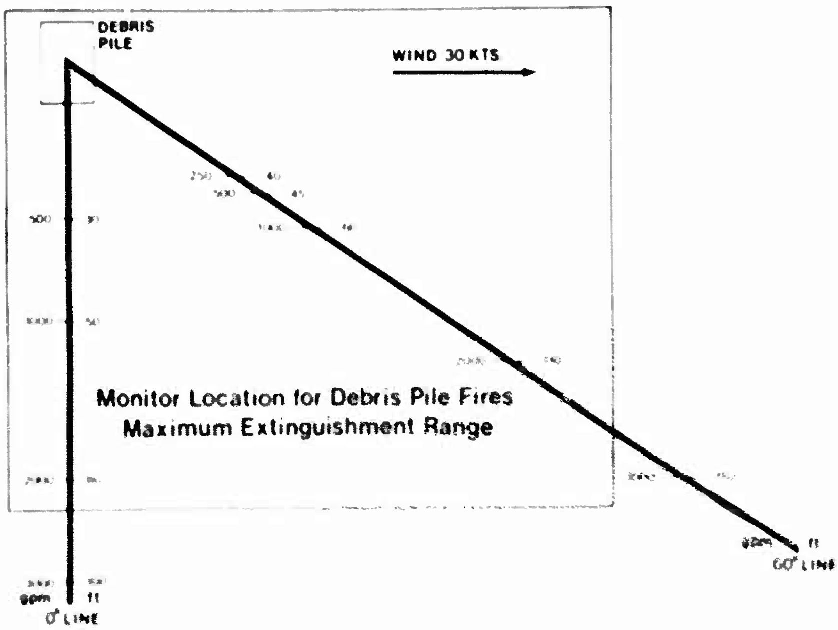


Fig. 31 - Monitor location for debris pile fires, maximum extinguishment range

At a 60° angle into the wind the range increase that was expected occurred and in this case closer to the expected. This test at 1,000 and 2,000 gpm was within 5% of what was expected. It should be remembered that the 60° angle provided a better angle on the debris pile for fire fighting than directly crosswind.

A factor in the decrease in range for extinguishment was the ability of the fire fighter/operator to effectively direct a stream in a 30 kt wind. In addition, the test limitation of extinguishment in 60 seconds may have had an impact upon the successful range. That is, given more time, the operator may have, in some cases, been successful in extinguishment.

6.12.4 Reach in Wind vs. No Wind

Stream reach in a no wind environment is greatly increased over crosswind reach especially with an increase in angle of elevation. Table 33 shows the significance of a small increase in elevation in the no wind environment. Reach in 0 kts wind at 10° elevation is approximately twice the crosswind reach. Much less increase occurs at 0° elevation as the stream impacts before it has attained maximum reach. This is especially true in flows above 1,000 gpm. This table clearly illustrates the problem of stream reach in a crosswind environment which exists on the flight deck. Other data in Appendix B indicated that stream reach in 0 kts wind increased until approximately 30° elevation.

Table 33 - Stream Reach in Crosswind vs. No Wind

(0° Elevation) 80 psi

Tip Size (in.)	Flow (gpm)	Crosswind (30 kts)	Wind (0 kts)
1-1/8	425	48	80
1-1/2	715	41	75
1-3/4	930	45	77
2 stack	1,200	40	80
2 Stang	1,085	70	70
2-1/4 Stang	1,530	87	105
2-1/2 Stang	2,020	95	110

(10° Elevation) 80 psi

Tip Size (in.)	Flow (gpm)	Crosswind (30 kts)	Wind (0 kts)
1-1/8	425	56	140
1-1/2	715	57	150
1-3/4	930	56	145
2 stack	1,200	47	150
2 Stang	1,085	64	120
2-1/4 Stang	1,530	110	190
2-1/2 Stang	2,020	125	220

7.0 RESULTS AND CONCLUSIONS

7.1 Normal Flow Washdown Systems

A. The most effective use of the carrier washdown system on pool fires requires AFFF solution in both the upwind and fire zones. This combination controlled a pool fire on a clear deck in a 30 knot wind in less than 20 seconds and extinguished it completely within 30 seconds.

B. Control and extinguishment were found to be faster in 30 knot winds than in 15 knot winds due to improved dispersion of the agent. Previous tests had demonstrated that extinguishment time is even longer in no wind conditions.

C. With wind present, use of the washdown fire fighting system in only the fire zone resulted in persistent "strips" of fire. Ordnance located in these "strips" would cook-off based on recorded temperatures, if other measures were not taken. Activation of the upwind zone eliminated these "strips," thereby removing the potential cook-off hazard.

D. Simultaneously discharging water in the upwind washdown zone and AFFF solution in the fire zone could not extinguish a pool or debris pile fire.

E. Water alone in the washdown system was ineffective in fire extinguishment and can spread pool fires.

F. Debris on the deck degraded the fire extinguishing capability of the washdown system.

G. Clogged flush deck nozzles increased fire control and extinguishment times significantly.

7.2 Increased Flow Washdown System

A. For a pool fire on an unobstructed deck, and using the upwind washdown nozzles only, doubling the flow rate from 30 to 60 gpm/nozzle reduced the control time from 30 to 16 seconds. No significant improvement was achieved by increasing the flow to 90 gpm/nozzle.

B. The washdown system alone did not extinguish a standard debris pile fire in a 30 knot wind even with flows as high as 250 gpm/nozzle.

C. In a 30 knot wind, a partial debris pile fire (upwind wall removed) was extinguished only with flows of at least 90 gpm/nozzle.

D. In applying washdown systems against a debris pile, agent flows of 90 gpm/nozzle or greater provided reductions in heat rise and increased cooling or ordnance.

7.3 Hand Lines

A. Against a 4,000 sq ft pool fire with an aircraft mock-up and 30 knot wind, both 1-1/2 in. and 2-1/2 in. hand lines were effective in achieving control in less than 30 seconds using AFFF.

B. While 2-1/2 in. hand lines, with their higher flow rates, cooled more effectively than 1-1/2 in. hand lines, they were less maneuverable in fire fighting. This was particularly true in 30 knot winds.

C. Use of two hand lines with AFFF solution gave control and extinguishment of pool fires in nearly half the time required for a single hand line. The best combination of two hand lines was one 1-1/2 in., for maneuverability, and one 2-1/2 in. providing more flow.

D. When using a combination of 1-1/2 in. and 2-1/2 in. hand lines, the use of water in the 2-1/2 in. (rather than AFFF solution) increased control and extinguishment times by as much as 50%. This was true for both aggressive fire fighting and with 50 ft stand-off tactics.

E. When ordnance was involved, the most effective strategy was to extinguish the fire promptly and then cool the ordnance rather than try to cool the ordnance and extinguish the fire simultaneously.

7.4 Washdown System and Hand Line Combination

A. Washdown systems combined with 1-1/2 in. and 2-1/2 in. hand lines were most effective when all systems used AFFF solutions. Use of water in any part of the system extends control and extinguishment times significantly.

B. With combinations of washdown systems and hand lines (or hand lines alone), very aggressive hand line tactics with AFFF solutions were required in

order to extinguish a running fuel fire in a debris pile.

7.5 Monitors

A. Within their effective range, all monitors (1,000 to 12,000 gpm) were found to extinguish debris pile fires, and to limit ordnance heat rise when the fire was attacked from the unshielded side.

B. None of the monitors could extinguish the debris pile fire when directed against the shielded side.

C. A 30 knot wind reduced the effective range of monitors in a crosswind attack on a debris pile fire to less than 1/3 the distance under no wind conditions. Crosswind velocities as low as 10 knots had significant impact on stream reach.

D. Monitors, within their effective range, controlled ordnance heat rise to minimal levels (less than 50°F) when operated against other than the shielded side of the debris pile.

E. The increase in effective crosswind range of monitors to extinguish debris fires was not proportional to increases in flow, higher flows giving progressively smaller increases in distance.

F. When monitors were operated at a 60° angle into the wind, with access to the unshielded side of the debris pile, the fire was generally extinguished at ranges 25% to 50% greater than in a 90° crosswind.

G. To be effective under crosswind conditions with access to partially shielded debris piles, monitors having flow rates in excess of 6,000 gpm/monitor would have to be located on opposite sides of the flight deck at 150 ft intervals, and would have to be erected to a height of 30 ft to clear parked aircraft.

H. Monitors mounted at 30 ft heights with flow rates of 1,000 gpm in crosswind attacks on the side of a debris pile could not extinguish running fuel fires located closer than 50 ft from the base of the pile due to shielding of the fire by the simulated aircraft wing (debris pile roof).

I. High flow monitors present a significant safety hazard to people and aircraft due to the high kinetic energy of the stream.

7.6 P-16 Improvements

A. Both PKP and Halon 1211, when used in combination with AFFF solutions, extinguished the debris pile fire. The twin agent unit hand line was difficult to use at distances over 20 ft from the reel, an additional fire fighter being needed to help pull hose.

B. At nominal agent flow rates of 5 lbs/s in 30 kt winds, neither single streams of PKP nor Halon 1211 alone extinguished the debris pile fire, even with the front wall removed. Two streams of Halon 1211, each flowing at 5 lbs/s were capable of extinguishing a standard debris pile fire, but would not have prevented ordnance cook-off for the preburn times used in these tests.

C. Neither PKP nor Halon 1211 was effective in cooling ordnance.

D. Increasing the turret flow rate from 100 gpm to 175 gpm provided an improvement in fire suppression capability, but in a crosswind, even with the higher flow rate, the P-16 could not extinguish the debris pile fire even when moved up as close as possible to the fire (10 ft).

7.7 Robot Tests

A. A robot can successfully manuever and attack a fire while pulling a fully charged 3 in. hose and discharging 500 gpm through its monitor.

B. Robots hold sufficient promise to justify further development and testing.

C. Stability is a problem for narrow width robots.

D. The robot used in these tests had a speed of 3-4 mph. A robot would require a significant increase in speed to be a viable unit for flight deck fire fighting.

7.8 Hose Control Devices

A. Hose control devices can be successfully placed on the deck, tied down and left unattended, thereby permitting fire fighters to withdraw from the immediate area while the nozzle continues to flow. These devices were shown to be effective for both fighting fires and cooling ordnance.

7.9 Weapons Cook-Off

A. When exposed to a JP-5 pool fire, the propellant inside the weapon will begin to increase in temperature within 15 seconds after exposure, and will usually experience a rate of heat rise of approximately 15 to 20°F/s under wind conditions.

B. Weapons in a debris pile fire will heat at lower rates, generally 8 to 10°F/s, in zero wind conditions.

C. When weapons in a pool fire are cooled by aggressive attack, using either water or AFFF solution with a 2-1/2 in. hand line, the propellant will cool at a rate of 30 to 40°F/s. Water alone, however, will not extinguish the fire whereas AFFF solution will.

D. From earlier experiments at the Naval Weapons Center, it was concluded that cook-off will generally occur when the missile motor case's interior temperature reaches 650°F.

E. Cook-off temperatures would occur in as little as 45 seconds for Sidewinder missiles in a debris pile fire and 67 seconds for Shrike missiles in a pool fire. The shorter cook-off time for the Sidewinder is due to its lighter motor case construction as compared with the Shrike missile.

F. Air cooling of weapons previously exposed to fire was virtually the same in wind velocities of 0 to 30 knots. Air cooling alone will provide a temperature reduction of 3 to 4°F/s.

G. A 2-1/2 in. hand line provides cooling of 25 to 35°F/s when applied from a 50 ft stand-off position.

H. Weapons on the deck will cease to heat and begin to cool at 5 to 10°F/s when the washdown system is used. Weapons suspended 5 ft or more above the deck will be out of range for the washdown system and hence will receive only air cooling.

I. Situations were occasionally observed where the agent did not actually extinguish the fire, but gave sufficient cooling so that ordnance heat rise was controlled, thus preventing cook-off.

J. "Stand-off" stream application showed a slower rate of cooling of a weapon in the debris pile than did aggressive hand line attack with either 1-1/2 in. or 2-1/2 in. hose (maximum of 15°F/s versus 60°F/s). Further, when cooling of the weapon did occur with "stand-off" streams, it began significantly later than was achieved with aggressive hand line attack.

K. Even the best available fire fighting system will not guarantee prevention of cook-off, due to the missile motor's sensitivity to heat. Extending the cook-off time of weapons is the most cost effective approach.

7.10 Stream Reach

A. Stream reach and accuracy are severely limited by crosswinds.

B. Increase in crosswind reach is not directly proportional to increase in flow.

C. Increase in crosswind reach is not directly proportional to increase in pressure.

D. Directing the stream slightly into the wind increases reach by as much as 30% over a 90° crosswind.

E. Effective reach in a 90° crosswind at 30 kts is approximately 1/3 of that under no wind conditions.

7.11 JP-4 Fires

A. Even under aggressive attack, a debris pile fire fueled by JP-4 instead of JP-5 could not be extinguished, even by two hose lines using AFFF solution.

B. The rate of temperature increase in the ordnance was approximately the same for JP-4 and JP-5 fires.

8.0 ACTIONS TAKEN

As a result of these tests several actions have been taken to date:

1. Fire fighting doctrine for flight decks has been changed and promulgated to the Fleet.

2. The effectiveness of the existing fire fighting systems, when installed and used properly, has been confirmed. This information has been promulgated to the Fleet.

3. A program has been undertaken to identify areas on aircraft carriers where additional fire fighting capacity may be required and to determine the capability of specific ship systems as installed, to effectively combat fires.

4. A training film for flight deck fire fighting has been prepared and issued [13].

5. The existing program for improving cook-off characteristics of weapons has been accelerated as part of the insensitive munitions program approved by CNO.

6. A program for further development of fire fighting robots has been implemented. Two prototypes were developed by the Robotics Laboratory of the Naval Surface Weapons Center and subjected to fire tests at the Naval Research Laboratory's fire test facility [14].

7. A program on fire protection for aircraft carrier bomb farms was instituted as a follow-on to these tests. The test program has been completed and a final report has been issued [15].

8. A reexamination of the hazards of JP-4 on flight decks is underway, and a preliminary report has been prepared under NAVSEA Project S1819, Aircraft Fire Suppression Systems [16].

9. A major new training initiative has been undertaken--Live Fire Team Training to be located at NAS MEMPHIS.

10. A hose control device which can provide a greater margin of safety for fire fighters is being provided to CV, LHA and LPD type ships [17].

11. Cost-benefit studies, particularly regarding application of AFFF extinguishing agent by increased flow washdown systems and large volume monitors, have been conducted.

12. High flow rate monitors have been eliminated from further consideration due to limited effectiveness, high cost and ship impact, and safety reasons.

13. Major new emphasis on implementing fire protection improvements into the Fleet has been undertaken under the direction of VADM James A. Webber, Chief Engineer, NAVSEA and Chairman of the CV Firefighting Flag Level Steering Committee.

14. Improvements to P-16 Flight Deck Firefighting Vehicle have been initiated by Naval Air Systems Command.

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GLOSSARY
ABBREVIATIONS

A/C	Aircraft
AFFF	Aqueous Film Forming Foam
d.p.	debris pile - is interpreted as meaning a full configuration as described in Test Facilities with a running fuel source cascade.
f.d.	flush deck (system or nozzle) - system of in-deck nozzles permanently installed in the flight deck of aircraft carriers for fire fighting with AFFF extinguishing agent or for chemical, biological and radiological agent decontamination (same as w.d.).
f.z.	fire zone - section of the aircraft carrier deck served by a group of flush deck nozzles in which an actual fire occurred or in which test fires are conducted.
PKP	purple colored potassium bicarbonate powder - the standard Navy dry chemical fire extinguishing agent.
PPS	pounds per second flow rate.
TAU	Twin Agent Unit
u.z.	upwind zone - section of aircraft carrier deck immediately forward and upwind of the fire zone (see f.z.).
w.d.	washdown (system or nozzles) same as f.d.

DEFINITIONS

AGENT - a fire extinguishing agent -- dry chemical (PKP), HALON 1211, AFFF and water are referred to as agents in this report.

AGENT APPLICATION TIME - the time, in seconds, that the agent is applied during any fire test.

AGENT-ON TIME - the time, in seconds, measured from ignition until agent application begins.

AGENT-OFF TIME - the time, in seconds, from ignition until the cessation of agent application.

AMBIENT WIND - naturally occurring air current from any direction with respect to the fire test area. Ambient crosswinds over 5 kts occurring during a fire test generally disqualified those test results.

ANEMOMETER - an instrument used to measure wind velocity. The hand held anemometer used for tests in this report was calibrated in nautical units per hour or knots (kts).

AQUEOUS FILM FORMING FOAM (AFFF) - a liquid concentrate compounded of fluorinated surfactants which, when dispensed from nozzles of fire fighting equipment, as a dilute aqueous solution, forms a stable, heat resistant foam. This foam, when used on liquid fuel fires, performs as both an extinguishing agent and as an inerting film to prevent re-ignition of the fire. The concentrate discussed in this report conformed to Type 6 material of MIL-F-24385 C. Type 6 concentrate is intended to be dispensed as a 6% solution in either fresh water or seawater.

COMBINED POOL AND DEBRIS PILE FIRE - a combination test fire where the debris pile is located in the pool fire area.

CONTROL TIME - the time, in seconds, from initiation of agent flow until 90% of the fire is extinguished.

COOLING RATE - a measure of the effectiveness of hardness, agents and tactics in cooling weapons which were exposed to test fires. The steady rate, in °F/second, at which heat was removed from instrumented missile motor cases during fire fighting tests. Measurement was made at a single thermocouple from the time when cooling began (after "agent-on") until "agent-off", generally over a period of 15 to 40 seconds. In some tests no cooling was observed at all.

COOK-OFF - when the temperature inside the shell of the instrumented missile motor cases used in these tests reached a temperature that would result in ignition or explosion - specified for these tests as 650°F maximum temperature or 150°F temperature rise after agent-on.

CRASH RESCUE VEHICLE - any of a series of vehicles designed to fight fires and assist in personnel rescue from aircraft crashes.

DEBRIS PILE - a standardized configuration of shielding and obstructions containing an internal JP-5 fuel fire supplied at 50 gpm and flowing down a cascade.

EXTINGUISHMENT TIME - the time, in seconds, from initiation of agent flow (agent-on time) until the fire is completely extinguished.

FLUSH DECK SYSTEM - see WASHDOWN SYSTEM

GENERATED WIND - 15 or 30 kt air currents, directed fore to aft, simulating natural winds over the flight deck test area, artificially induced by aircraft engine propellers, air boat engines, or other wind machines.

HAND LINE, 1-1/2 IN. - standard MIL SPEC hard hose of the type used on ships for flight deck fire fighting, equipped with 125 gpm MIL SPEC nozzles.

HAND LINE, 2-1/2 IN. - standard MIL SPEC soft hose of the type used on ships for flight deck fire fighting, equipped with a 250 gpm MIL SPEC nozzle.

HALON 1211 - halogenated, vaporizing liquid fire extinguishing agent.

HOSE CONTROL DEVICE - a portable stand to hold a 1-1/2 in. or 2-1/2 in. hose nozzle allowing a stream to be directed at a target; may be tied down and left unmanned.

HEAT RISE - the temperature increase of a thermocouple at the inside surface of Shrike or Sidewinder missile motor cases measured from "agent-on" time until either heating ceased or agent flow was terminated ("agent-off" time). This measure was established in order to evaluate and compare the effectiveness of fire fighting and weapons cooling techniques.

HEATING RATE - a measure of the heating vulnerability of the instrumented missile motor cases used in these tests by the pool and debris pile fires. The steady rate in °F/second, at

which heating was observed on a single thermocouple between ignition of the test fire and until "agent-on" time.

MONITOR - a portable or stationary device equipped with a nozzle to dispense an extinguishing agent stream. These may be permanently mounted on structures or vehicles or may be set in place during use.

NOZZLE, STRAIGHT BORE - a non-adjustable nozzle designed to provide a solid stream.

NOZZLE, VARIABLE PATTERN - a nozzle designed to dispense variable stream patterns from straight stream to fog spray at a constant flow rate. These included two types of nozzles, those which can be adjusted while flowing and those which can be adjusted only when dry.

NOZZLE, FLUSH DECK - a nozzle designed to be permanently installed flush with the flight deck and provide an umbrella shaped spray pattern. These nozzles are installed in groups which protect discrete zones of the flight deck.

ORDNANCE - sand-filled Shrike or Sidewinder missile motor cases equipped with thermocouples to provide heating and cooling data in fire tests.

ORDNANCE COOLING - the rate of decrease in temperature resulting from either extinguishing agent or air cooling as determined by thermocouples of the Shrike and Sidewinder missile motor cases.

POOL FIRE - a two dimensional fire simulating an actual fuel spill. These fires were contained in a diked area and with few exceptions, usually consisted of 4,000 sq ft. The 4,000 sq ft fire was fueled with 1,200 gallons of JP-5 on a water substrate used for leveling purposes.

PREBURN TIME - the time from ignition to "agent-on", provided in order to insure complete fire development.

P-16 - see CRASH RESCUE VEHICLE.

SHIELDED SIDE - the side of the standard debris pile which is shielded from direct extinguishing agent access by a tilted obstacle simulating an aircraft wing.

TAILWIND - ambient wind currents directed from the aft end of the simulated aircraft carrier flight deck (opposite from the direction of generated wind).

THERMOCOUPLE - type K (chromel-alumel) bi-metallic temperature sensors used to determine ordnance heat rise and cooling rates.

TWIN AGENT UNIT (TAU) - a dual nozzle device designed to permit a single operator to simultaneously dispense both dry chemical agent (PKP) and aqueous film forming foam (AFFF). The similar unit on the P-16 vehicle was modified in this study to dispense liquid Halon 1211, in lieu of PKP.

UNSHIELDED SIDE - the side of the standard debris pile that is left open permitting agent access to the fire located under a tilted obstruction which simulates an aircraft wing.

WASHDOWN SYSTEM - a seawater system of pumps, piping and nozzles originally designed to wet the exterior of the ship and flush nuclear, biological and chemical agents. This system was later modified to provide fire extinguishing capability by dispensing AFFF though flush deck edge nozzles.

APPENDIX A

CONSOLIDATED DATA SHEETS

FIRE TESTS

FIRE TEST LEGEND

TEST NUMBERS

A-1 THRU A-56	NIMITZ TESTS
B-1 THRU B-10	MONITOR SCOPING TESTS PHASE I
C-1 THRU C-15	MONITOR SCOPING TESTS PHASE II
D-1 THRU D-29	SYSTEMATIC TESTS PHASE II
E-1 THRU E-51	CONCEPTS EVALUATION TESTS
F-1 THRU F-17	VARIABLE HEIGHT MONITOR TESTS
G-1 THRU G-21	CONCEPTS AND REFINEMENT TESTS
H-1 THRU H-10	P-16 IMPROVEMENT TESTS

AGENT

A - AFFF

W - Water

TYPE OF FIRE

POOL - Pool Fire (400 sq.ft. unless otherwise noted)

D.P. - Debris Pile (Standard debris pile fire and shielded side unless attack otherwise noted)

WEAPON TYPE AND POSITION

SK - Shrike

SW - Sidewinder

WING - Mounted under wing of aircraft mock-up

D.P. - Installed in debris pile

TIMES ARE ALL IN SECONDS

DEGREES TEMPERATURE ARE ALL IN FAHRENHEIT

TEST #	EQUIPMENT	AGENT	FLOW (gpm)	FIRE	WIND (kts)	WEAPON	PRE-BURN	AGENT RUN	CONTROL TIME	EXT.	TEMP @ AGENT ON	HEAT RISE	COOL RATE
A-1	UZ,FZ	AFFF	30	POOL	30	SK/WING	37	40	25	30	347	9	17
A-2	F6	AFFF	30	POOL	30	SK/WING	42	80	NO	55%	461	170	10
A-3	UZ,FZ	W / AFFF	30	POOL	30	SK/WING	57	130	NO	40%	802	397	NONE
A-3R	UZ,FZ	W / AFFF	30	POOL	30	SK/WING	55	90	90	NO	510	8	9
A-4	UZ,FZ	W	30	POOL	30	SK/WING	42	90	NO	50%	457	40	NO
A-5	UZ,FZ	W	30	POOL	15	SK/WING	45	67	NO	0%	445	170	10
A-6	UZ,FZ,1 1/2"	AFFF	30	POOL	15	SK/WING	42	70	30	70	591	27	5
A-7	UZ,FZ	W / AFFF	15	POOL	15	SK/WING	43	80	45	95%	NO	NO	NO
A-8	2 1/2"	AFFF	30	POOL	30	SK/WING	41	50	27	50	526	18	5
A-9	1 1/2,2 1/2"	AFFF	30	POOL	30	SK/WING	35	25	20	25	520	65	4
A-10	1 1/2"	AFFF	125	POOL	8-10	SK/WING	75	51	35	42	798	82	7
	2 1/2"	AFFF	250		25-30			51	35				
A-11	1 1/2"	AFFF	LOW P	POOL	5-10	SK/WING	61	142	115	136	658	473	5
	2 1/2"	AFFF	S OFF		30			138					
A-12	1 1/2"	AFFF	125	POOL	35	SK/WING	48	67	37	56	620	6	4
A-12R	1 1/2"	AFFF	125	POOL	30	SK/WING	32	57	27	42	620	28	3
A-13	1 1/2"	AFFF	125	POOL	30	SK/WING	47	86	49	56	619	9	13
A-14	2 1/2"	AFFF	250	POOL	30	SK/WING	40	74	42	50	530	36	13
A-15	1 1/2"	AFFF	125	POOL	30	SK/WING	37	85	26	47	550	38	15
	2 1/2"	W	250					60					
A-16	1 1/2"	AFFF	125	POOL	30	SK/WING	33	72	39	66	496	30	36
	2 1/2"	W	250					75					
A-17	1 1/2"	AFFF	125	POOL	30	SK/WING	33	70	25	48	586	29	20
	2 1/2"		250					65					
A-18	1 1/2"	AFFF	125	POOL	30	SK/WING	38	59	30	53	530	11	20
	2 1/2"		250					65					
A-19	UZ	W	30	POOL	30	SK/WING	32	53	33	54	521	85	20
	FZ	AFFF						54					
	1 1/2"	AFFF	125					45					
	2 1/2"	W	250					47					

A-20	UZ	AFFF	30	POOL	30	SK/WING	37	44	18	26	548	29	16
	FZ	AFFF						43					
	1 1/2"	AFFF	125					23					
	2 1/2"	AFFF	250					31					
A-21	UZ	AFFF	30	POOL	15	SK/WING	32	35	23	30	619	16	16
	FZ	AFFF						39					
	1 1/2"	AFFF	125					24					
	2 1/2"	AFFF	250					30					
A-22	UZ	W	30	POOL	15	SK/WING	33	44	29	44	603	6	34
	FZ	AFFF						45					
	1 1/2"	AFFF	125					37					
	2 1/2"	W	250					40					
A-23	1 1/2"	AFFF	125	POOL	30	SK/WING	43	62	38	55	540	62	25
	2 1/2"	W	250					62					
A-24	1 1/2"	AFFF	125	POOL	35	SK/WING	47	61	18	33	535	46	25
	2 1/2"	AFFF	250					62					
A-25	UZ	AFFF	30	POOL / DP	30	SK/WING	43	65	20	33P	512	7	16
	FZ	AFFF	30			SW / DP		65			1087	201	9
	1 1/2"	AFFF	125					58					
	2 1/2"	AFFF	250					57					
A-26	UZ	AFFF	30	POOL / DP	15	SK/WING	72	90	39	31P	76[illegible]	154	3
	FZ	AFFF	30			SW / DP		80		720P	585	363	11
	1 1/2"	AFFF	125					75					
	2 1/2"	AFFF	250					75					
A-27	UZ	W	30	POOL / DP	30	SK/WING	61	110	46	38P	553	47	6
	FZ	AFFF	30			SW / DP		110		1100P	644	328	6
	1 1/2"	AFFF	125					108					
	2 1/2"	W	250					106					
A-28	1 1/2"	AFFF	125	POOL	30	SK/WING	58	57	22	47P	507	17	5
	2 1/2"	AFFF	250	DP		SW / DP		53		350P	776	191	8
A-29	1 1/2"	AFFF	125	POOL	0	SK/WING	46	104	52	65P	709	191	4
	2 1/2"	AFFF	250	DP		SW / DP		100		850P	793	167	35
A-30	UZ	AFFF	30	POOL / DP	30-35	SK/WING	40	120	40	70P	474	32	3
				NO RUN FUEL									
	FZ	AFFF	30			SW / DP		120		1130P	428	267	10
A-25R	UZ	AFFF	30	POOL / DP	30	SK/WING	37	45	22	30P	486	18	11
	FZ					SW / DP		45		500P	645	448	9
	1 1/2"		125					45					
	2 1/2"		250					46					
A-27R	UZ	W	30	POOL / DP	30	SK/WING	59	130	60	73P	473	39	25
	FZ	AFFF	30			SW / DP		130		1120P	790	332	3
	1 1/2"	AFFF	125					123					
	2 1/2"	W	250					123					

A-27R1	UZ	W	30	POOL / DP	30	SK/WING	38	132	40	52P	515	33	26
	FZ	AFFF	30			SW / DP		132		122DP	509	464	4
	1 1/2"	AFFF	125					117					
	2 1/2"	W	250					117					
A-9R	1 1/2"	AFFF	125	POOL	30	SK/WING	50	42	13	19	472	50	3
	2 1/2"	AFFF	250					30					
A-1R	UZ,FZ	AFFF	30	POOL	30	SK/WING	34	55	24	45	573	81	5
A-31	2 1/2"	W	250	POOL	20	SK/DECK	43	130	ND	ND	514	10	31
	(swept fire off/on 130 sec.)			(200 sq ft)									
A-32	2 1/2"	AFFF	250	POOL	20	SK/DECK	49	130	5	9	559	0	38
	(swept fire off/on 130 sec.)			(200 sq ft)									
A-33	2 1/2"	AFFF	250	POOL	20	SK/DECK	42	90	4	8	573	0	42
	(90 sec.)			(200 sq ft)									
A-34	2 1/2"	W	250	POOL	10	SK/DECK	51	90	ND	ND	543	41	42
				(200 sq ft)									
A-35	1 1/2"	AFFF	125	POOL	5	SK/WING	35	183	135	170	586	649	413
	2 1/2"	AFFF	250					147					
	(attack into wind-firefighters hands blistered)												
A-36	2 1/2"	AFFF	250	POOL	30	SK/WING	51	92	21	85	516	52	3
A-37	2 1/2"	W	250	POOL	30	SK/WING	40	73	30	44	642	6	4
	2 1/2"	AFFF	250					77					
A-38	UZ	W	30	POOL(tires)	30	SK/WING	41	108	140	159P	589	135	5
	FZ	W	30					108		180T			
	1 1/2"	AFFF	125	(161 sec. used to complete extinguishment)				76					
A-39	UZ	AFFF	30	POOL(tires)	30	SK/WING	38	50	24	35P	677	77	4
	FZ	AFFF	30					50		75T			
A-40	UZ	W	30	POOL(tires)	35	SK/WING	46	142	80	110P	839	100	3
	FZ	AFFF	30					136		130T			
A-41A	1 1/2"	AFFF	125	DP / JP4	15	SW / DP	30	56	ND	ND	406	222	8
A-41B	2 1/2"	AFFF	250	DP / JP4	15	SW / DP	5	52	ND	ND	267	18	ND
A-41C	TAU AFFF/PKP	AFFF /PKP	50 4-5 pps	DP / JP4	15	SW / DP	23	51	ND	ND	430	64	20
A-41D	1 1/2"	AFFF	125	DP / JP4	15	SW / DP	5	96	ND	ND	262	59	ND
	2 1/2"	AFFF	250										
	(side by side)												
A-42	1 1/2"	AFFF	125	DP / JP4	15	SW / DP	49	75	ND	ND	453	230	17
	2 1/2"	AFFF	250										

A-43	MB-5 TAU AFFF (PKP)			DP / JP4	13	SW / DP	52	115	COLD FIRE				
A-44	(2) 30lb PKP			POOL	25-30	SK/DECK	37	43	NO	NO			
	(1) 17lb HALON 1211			200 sq ft									
	(extinguished by short burst from 1 1/2" handline at 43 sec.)												
A-45	MB-5 TAU AFFF	AFFF	50	DP / JP5	15	SW / DP	77	50		45	401	161	3
	PKP	PKP	4-5 pps										
A-46	1 1/2" (port)	AFFF	125	DP	18-20	SW / DP	61	35		31	536	78	3
	1 1/2" (star.)	AFFF	125 (one from each side)										
A-47	MONITOR 0 deg.	AFFF	1000	DP shielded	10-12	SW / DP	53	100	NO	NO	500	180	8
	100 ft / 30 degree fog												
A-48	MONITOR 90 deg.	AFFF	1000	DP	8-12	SW / DP	69	90	NO	NO	504	492	0
	40 ft / 30 degree fog changed to s/s at 90 sec. (crosswind side attack)												
A-49	MONITOR 0 deg.			DP unshielded	0	SW / DP	56	60	NO	NO	492	290	0
	over AC mock-up at DP open side (obsructed C mock-up)												
A-50	MONITOR 90 deg.	AFFF	450	DP	0	SW / DP	33	50	NO	45	500	146	12
	40 ft range												
	MONITOR 270 deg.	AFFF	950					50					
	55 ft range												
A-51	MONITOR 90 deg.	AFFF	450	DP	1	SW / DP	63	62		62	480	33	7
	40 ft range												
	MONITOR 270 deg.	AFFF	850										
	55 ft range												
A-52	UZ	W	30	POOL / DP (no run fuel)	30	SK/WING	53	60	85	90P	658	65	4
	FZ	AFFF	30			SW / DP		103		130DP	424	194	3
	1 1/2"	AFFF	125 (100 sec. to complete extinguishment)					60					
A-53	UZ	AFFF	30	POOL / DP (no run fuel)	30	SK/WING	64	131	100	120P	667	75	4
	FZ												
	1 1/2"	AFFF	125 (159 sec. when flashback occurred)					68					
A-54	UZ	W	30	POOL / DP (with tires)	1-2	SK/WING	49	323	190	230P	410	456	12
	FZ (4 plug nozzle)	AFFF	30 (unplugged)		30	SW / DP		330		330DP	754	551	13
	1 1/2"	AFFF	125 (212 sec./no cooling req. until 190 sec)					183					
A-55	UZ	AFFF	30	POOL / DP (with tires)	1	SK/WING	34	113	40	60P	426	74	15
	FZ	AFFF	30		30	SW / DP		111		1000P	158	627	9
	1 1/2"	AFFF	125 (on 69 sec)					110					
	2 1/2"	AFFF	250 (on 69 sec)					110					

A-56	UZ	W	30	POOL / DP	30	SK/WING	121	462	195	235P	1026	0	14
				(with tires)									
	FZ	AFFF				SW / DP		462		4200P	1193	199	4
	(four plugged nozzles)												
	1 1/2"	AFFF	125 (on 253 se.)					338		450T			
	2 1/2"	W	250 (on 195sec.)					338					
B-1	5000 GPM MON.	AFFF	5400	DP	0	SW / DP	52	65	NO	NO	626	175	NO
	(245 front ctr)			(shielded side)									
B-2	6000 GPM MON.	AFFF	6300	DP	0	SW / DP	53	65	NO	NO	706	430	NO
	(160 front ctr)			(shielded side)									
B-3	1000 GPM MON.	AFFF	1066	DP	12-13	SW / DP	137	61	NO	NO	89	270	NO
	(95 front ctr)			(unshielded side)									
B-4	2000 GPM MON.	AFFF	1980	DP	8-10	SW / DP	53	61	NO	YES	557	1	5
	(95 front ctr)			(unshielded side)									
B-5	1000 GPM MON.	AFFF	1140	DP	1-3	SW / DP	46	61	NO	YES	434	6	6
	(95 front ctr)			(unshielded side)									
B-6	1000 GPM STBD	AFFF	1000	DP	0	SW / DP	53	55	NO	YES	781	68	20
	(110 range-50 from c/l)			(unshielded side)									
	1000 GPM PORT		1000										
	(95 range-50 from c/l)												
B-7	1000 GPM STBD	AFFF	1000	DP	30	SW / DP	67	60	NO	NO	1054	38	18
	(110 range-50 from c/l)			(unshielded side)									
	1000 GPM STBD		1000										
	(95 range-50 from c/l)												
B-8	1000 GPM MON.	AFFF	1109	DP	1-2	SW / DP	48	61	NO	YES	749	26	13
	(70 front ctr)			(unshielded side)									
	(20 from c/l)												
B-9	500 GPM MON>	AFFF	500	DP	4	SW / DP	55	62	NO	YES	753	171	14
	(70 front ctr)			(unshielded side)									
	(20 from c/l)												
B-10	2000 GPM MON.	AFFF	1900	DP UNSHIELDED	30	SK/FOREWING	80	65	NO	YES	561	57	4
	(110 front ctr)			POOL 4000 SF		SK/AFT WING				10	---NO HEATING---		
	(55 from c/l)					SW / DP					600	80	9
	1000 GPM MON.	AFFF	900				85	60	NO				
	(95 from front)												
	(55 from c/l)												
	UZ	AFFF	30				74						
	FZ	AFFF	30										
C-1	1 1/2"	W		DP	0	SW / DP	50	125	NO	NO	429	172	NO
	(over wall 70 sec)												
	1 1/2"	AFFF		DP	0	SW / DF		42		42	688	12	10
C-2	250 GPM MON.	AFFF	250	DP/UNSHIELDED	0	SW / DP				YES	429	231	14
	(55 front ctr)												

C-3	250 GPM MON.	AFFF	250	DP/UNSHIELDED	0	SW / DP		62		YES	451	87	26
	(56 front ctr)												
C-4	12000 GPM MON.	AFFF	11400	DP/UNSHIELDED	0	SW / DP	80	60	NO	NO	688	36	9
	(350' range)												
C-5	12000 GPM MON.	AFFF	11500	DP/UNSHIELDED	0	SW / DP	70	60	NO	NO	676	202	0
	(350' range)												
C-6	250 GPM MON.	AFFF	250	DP/UNSHIELDED	0	SW / DP	62	60		YES	762	43	8
C-7	1000 GPM MON.	AFFF	1140	DP/UNSHIELDED	0	SW / DP	54	61		YES	896	122	14
	(110' range)												
	1000 GPM MON.												
	(150' range)												
C-8	1000 GPM MON.	AFFF	1200	POOL	0	SK/WING	70	40	NO	20	879	220	19
	(110' range)			7500 sq ft		SK/DECK							
	1000 GPM MON.	AFFF	1200		0						1094	137	7
	(150' range) [monitors 125' apart]												
C-9	12000 GPM MON.	AFFF	11000	POOL	0	SK/WING			NO	15	1061	173	9
	(350' range)			7500 sq ft		SK/DECK					301	280	2
C-10	2000 GPM MON.	AFFF	2000	DP	30	SW / DP	53	72	NO	YES	789	27	40
	(50' range-crosswind, side attack)												
C-11	1000 GPM MON.	AFFF	995	DP	30	SW / DP	65	62	NO	YES	789	27	40
	(50' range-crosswind, side attack)												
C-12	1000 GPM MON.	AFFF	1010	DP	0	SW / DP	58	60	NO	YES	439	0	14
	(side attack knocked 10 blockhole in DP wall at 50'range)												
C-13	1000 GPM MON.	AFFF	943	DP	0	SW / DP	53	60	NO	YES	365	0	23
	(70' range-side attack 60 degrees)												
C-14	1000 GPM MON.	AFFF	950	DP	30	SW / DP	78	62	NO	NO	540	598	28
	(50' range-side attack crosswind)												
C-15	1000 GPM MON.	AFFF	950	DP/UNSHIELDD	30	SW / DP	64	70	NO	YES	575	1185	0
	(70' range-side attack 60 degrees)												
D-1	1000 GPM MON.	AFFF	980	DP	30	SK / DP	77	60	NO	YES	643	455	29
	(50' range)					SW / DP					1244	46	36
D-2	1000 GPM MON.	AFFF	1018	DP	30	SK / DP		60	NO	NO	989	494	NO
	(60' range)					SW / DP	66				1026	257	NO
D-3	2000 GPM MON.	AFFF	2113	DP	30	SK / DP	90	60	NO	NO	557	413	7
	(100'range)					SW / DP					1052	100	15
D-4	3000 GPM MON.	AFFF	3827	DP	30	SK / DP	62	60	NO	YES	414	379	60
	(100' range)					SW / DP					568	151	13
D-5	3000 GPM MON.	AFFF	3182	DP	30	SK / DP	61	60	NO	YES	483	70	15
	(100' range)					SW / DP					302	152	12

D-6	3000 GPM MON.	AFFF	3093	DP	30	SK / DP		60	NO	NO	341	307	70
	(110' range)					SW / DP					506	173	12
D-7	2000 GPM MON.	AFFF	2054	DP	30	SK / DP	59	60	NO	NO	0	0	0
	(90' range)					SW / DP					707	161	26
D-8	2000 GPM MON.	AFFF	2058	DP	30	SK / DP	67	60	NO	YES	479	31	52
	(80' range)					SW / DP					484	23	29
D-9	1000 GPM MON.	AFFF	993	DP	30	SK / DP	85	60	NO	NO	783	26	9
	(70' range at 60 degrees to wind)					SW / DP					360	167	9
D-10	1000 GPM MON.	AFFF	1014	DP	30	SK / DP	64	60	NO	NO	485	188	15
	(70' range at 60 degrees to wind)					SW / DP					681	60	10
D-11	1000 GPM MON.	AFFF	1063	DP	30	SK / DP	63	60	NO	YES	621	31	3
	(60' range at 60 degrees to wind)					SW / DP					293	24	4
D-12	2000 GPM MON.	AFFF	2196	DP	30	SK / DP	58	60	NO	YES	700	43	
	(100' range at 60 degrees to wind)					SW / DP					298	173	
D-13	2000 GPM MON.	AFFF	2029	DP	30	SK / DP	65	60	NO	YES	719	24	12
	(110' range at 60 degrees to wind)					SW / DP					715	168	50
D-14	3000 GPM MON.	AFFF	3377	DP	30	SK / DP	63	60	NO	YES	352	249	6
	(150' range at 60 degrees to wind)					SW / DP					271	239	11
D-15	100 GPM MON.	AFFF	95	DP	30	SK / DP	65	60	NO	NO	740	75	NO
	(30' range)					SW / DP				DATA NOT RELIABLE			
D-16	250 GPM MON.	AFFF	250	DP	30	SK / DP	56	60	NO		DATA NOT		
	(30' range)					SW / DP					AVAILABLE		
D-17	500 GPM MON.	AFFF	500	DP	30	SK / DP	60	60	NO	YES	617	261	25
	(30' range)					SW / DP					665	14	15
D-18	500 GPM MON.	AFFF	500	DP	30	SK / DP	60	60	NO	YES	572	67	9
	(45' range at 60 degrees to wind)					SW / DP					686	39	15
D-19	4 BETE MD NOZ.	AFFF	1400	DP	0	SK / DP	61	60	NO	YES		NO DATA	
	20' apt on 4 sides of DP(300GPM) F2,100 psi					SW / DP							
D-20	4 BETE MD NOZ.	AFFF	1094	DP	30	SK / DP	65	60	NO	NO		NO DATA	
	20' apt on 4 sides of DP(300GPM) F2,50 psi					SW / DP							
D-21	4 BETE MD NOZ.	AFFF	1371	DP	30	SK / DP	75	60	NO	NO		NO DATA	
	20' apt on 4 sides of DP(300GPM) F2,90 psi					SW / DP							
D-22	1000 GPM MON.	AFFF	830	DP	0	SK / DP	65	139		YES			
	(50' range-30' height)					SW / DP							
D-23	1000 GPM MON.	AFFF	874	DP	30	SK / DP	66	132		NO			
	(50' range-30' height)					SW / DP							
D-24	1000 GPM MON.	AFFF	870	DP	30	SK / DP	67	127		YES			
	(50' range-30' height)					SW / DP							

D-25	4000 GPM MON.	AFFF	4010	DP	30	SK / DP	83		NO			
	(140' range)					SW / DP						
D-26	1000 GPM MON.	AFFF	1117	DP	30	SK / DP	55		YES			
	(100' range into wind)					SW / DP						
D-27	1000 GPM MPR.	AFFF	1117	DP	30	SK / DP	60	60	NO	165	17	
	(40' range)					SW / DP						
D-28	1000 GPM MPR.	AFFF		DP	0	SK / DP		60	YES	140	244	
	(40' range)					SW / DP			30			
D-29	AGENT INJECTED	AFFF	300POOL/900 sqft			no ordnance	60	60	YES			
	INTO AIRSTREAM FROM WIND MACHINE FROM 30'					in pool			30			
E-1	1 1/2" at 25'	AFFF	95	DP	30	SK / DP	63	60	NO	983	665	NO
	(standoff at 270 deg.)					SW / DP				688	632	NO
E-2	250 GPM MON.	AFFF	250	DP	30	SK / DP	64	60	NO	657	179	5
	(30' range/270 deg.)					SW / DP				1173	5	8
E-3	250 GPM MON.	AFFF	250	DP	30	SK / DP	63	60	YES	572	212	10
	(40' range/60 deg.)					SW / DP				691	252	20
E-4	2000 GPM MON.	AFFF	2139	DP	30	SK / DP	71	60	NO		N O D A A	
	(100' range/30 deg. to wind)					SW / DP						
E-5	125 GPM P-16	AFFF	1000P/UNSHIELDED		0	SK / DP	64	60	NO	649	139	8
	TURRET from 25'					SW / DP				369	14	0
E-6	125 GPM P-16	AFFF	100/400P/UNSHIELDED		0	SK / DP	58	60	YES	768	82	20
	TURRET and 60 GPM HL at 30'					SW / DP				383	4	NO
E-7	2 1/2"/250 GPM	AFFF	250	DP	0	SK / DP	62	60	NO	570	165	6
	(50' standoff)					SW / DP				514	0	10
E-8	2 1/2"/250 GPM	AFFF	250	DP	0	SK / DP		60	YES	556	103	6
	(50' standoff)					SW / DP				389	0	10
E-9	2 1/2"/250 GPM	AFFF	250	DP	1-2	SK / DP	64	60	YES	579	71	10
	(50' standoff)					SW / DP						
	2 1/2"/250 GPM	AFFF								688	0	30
	(50' standoff)											
E-10	2 1/2"/250 GPM	AFFF	250	DP	1-2	SK / DP	62	60	YES	631	57	3
	(50' standoff)					SW / DP				858	117	30
E-11	HONDA ATV	AFFF	125	DP	3-4	SK / DP	65	60	YES	541	126	3
	1 1/2"/125 GPM from 25-30 ft.					SW / DP				835	140	10
E-12	2000 GPM MON.	AFFF	2104	DP	30	SK / DP	69	60	YES	567	79	15
	(95' range/30 deg. to wind					SW / DP				801	129	40
E-13	1000 GPM MON.	AFFF	1013	DP	0	SK / DP	72	60	YES	329	21	10
	(150' range/12 deg. elev. max range)					SW / DP				1037	27	30

E-14	1000 GPM MON.	AFFF	977	DP	0	SK / DP	57	60	NO	455	151	10
	(235' range/23 deg. elev. max range)					SW / DP				744	96	40
E-15	1000 GPM MON.	AFFF	977	DP	0	SK / DP	60	60	YES	582	15	15
	(235' range/32 and 10 deg. el. max. range)					SW / DP				N O	D A T	A
E-16	4000 GPM MON.	AFFF	4000	DP	0	SK / DP	60	60	YES	632	26	8
	(325' range/12 deg. elev.)					SW / DP				487	56	40
E-17	6 std. WD NOZZ	AFFF	528	DP	30	SK / DP	77	60	NO	484	299	NO
	(bored out 3/4" at 30 psi)					SW / DP				685	316	30
E-18	6 std. WD NOZZ	AFFF	500	DP	30	SK / DP	61	60	NO	596	271	NO
	(30 psi)					SW / DP				743	183	20
E-19	6 std. WD NOZZ	AFFF	739	DP	30	SK / DP	61	60	NO	552	159	NO
	(bored out 3/4" at 100 psi)					SW / DP				755	183	20
E-20	6 std. WD NOZZ	AFFF	180	DP	30	SK / DP	75	60	NO	670	465	NO
	(30 psi)					SW / DP				763	527	NO
E-21	6 std. WD NOZZ	AFFF	360	DP	30	SK / DP	60	60	NO	785	462	NO
	(120 psi)					SW / DP				944	327	NO
E-22	6 BETE WD NOZZ	AFFF	1419	DP	30	SK / DP	106	60	NO	650	200	13
	(40 psi)					SW / DP				908	10	29
E-23	2 1/2" at 60'	AFFF	250	DP	30	SK / DP	60	60	YES	650	200	13
						SW / DP						
	2 1/2" at 60'	AFFF	[one PORT,one STARBOARD]							765	95	28
E-24	2 1/2" at 60'	AFFF	250	DP	30	SK / DP	83	60	YES	755	91	30
						SW / DP						
	2 1/2" at 60'	AFFF	[one PORT, one STARBOARD]							956	110	15
E-25	6 std. WD NOZZ	AFFF	216	DP	30	SK / DP	58	60	NO	531	242	NO
	(40 psi)					SW / DP				672	409	15
E-26	6 std. WD NOZZ	AFFF	360	DP	30	SK / DP	55	60	NO	587	249	NO
	(120 psi)		no front wall			SW / DP				662	6	23
E-27	6 std. WD NOZZ	AFFF	500	DP	30	SK / DP	56	60	YES	669	81	14
	(30 psi)		no front wall			SW / DP			45	626	10	35
E-28	6 std. WD NOZZ	AFFF		DP	30	SK / DP	56	60	YES	724	90	7
	(155 psi)		no front wall			SW / DP			30	407	36	28
E-29	6 BETE WD NOZZ	AFFF	1392	DP	30	SK / DP	55	60	YES	736	76	5
	(40 psi)		no front wall			SW / DP			45	679	30	35
E-30	6 std. WD NOZZ	AFFF	180	DP	30	SK / DP	70	60	NO	756	103	3
	(30 psi)		all walls down			SW / DP				663	39	10
E-31	1 1/2"	AFFF	125	DP	30	SK / DP	36	60	YES	457	106	3
			all walls down			SW / DP			45	460	38	30

	E-32	HALON	1211	5 pps	DP	30	SK / DP	65	60		NO	457	106	3
					unshielded		SW / DP					460	38	30
	E-33	PKP		4 pps	DP	30	SK / DP	52	60		NO	522	522	0
					unshielded		SW / DP					214	752	0
	E-34	HALON	1211		DP	25	SK / DP	81	60		NO	522	515	5
		P16 50' stand off		5 pps	unshielded		SW / DP					214	452	5
		P17 (did not operate)												
	E-35	HALON			DP		SK / DP	53	60		YES	577	317	5
		P16 40' standoff		5 pps	unshielded	30	SW / DP					572	346	5
		P17 40' standoff		5 pps										
	E-36	P16 TURRET	AFFF	125	DP		SK / DP	59	60		YES	450	442	4
		nursed/60' stand off			unshielded	30	SW / DP					600	65	17
	E-37	500 GPM MON.	AFFF	500	DP	30	SK / DP	69	60		YES	207	125	20
		(portable/50')			unshielded		SW / DP					633	121	21
	E-38	P16 TAU	PKP	4 pps	DP	30	SK / DP	50	60		YES	556	495	5
		(40' range)	AFFF	60	unshielded		SW / DP					188	246	13
		standoff												
	E-39	P16 TAU			DP	30	SK / DP	50	60		YES	575	385	12
		HALON	1211	5 pps	unshielded		SW / DP					140	NO	NO
		40' standoff	AFFF	60										
	E-40	P16 TURRET	AFFF	250	DP	30	SK / DP	59	60		YES	603	222	15
		(50' standoff)			unshielded		SW / DP					492	71	15
	E-41	WAT-R-WALL	AFFF	100	DP	25	SK / DP	60	60		NO	NO DATA		
		(30' range)			unshielded		SW / DP							
	E-42	500 GPM MON.			DP	30	SK / DP	69	60		YES	280	171	15
		(portable/45' at 60 degrees)			unshielded		SW / DP					440	154	40
	E-43	2 1/2"	AFFF	250	DP	30	SK / DP	65	60		YES	487	98	16
		2 1/2"			unshielded		SW / DP					809	61	21
		(both in hose controls/40' at 60 degrees to wind)												
	E-44	1000 GPM MON.	AFFF	995	DP	30	SK / DP	91	60		YES	679	58	30
		(50' range/crosswind)			unshielded		SW / DP					509	118	2
	E-45	2000 GPM MON.	AFFF	1961	DP	30	SK / DP	285	60		YES	856	0	8
		(80' range/crosswind)			unshielded		SW / DP					704	34	50
	E-46	P16 HALON	1211	5 pps	DP	5-8	SK / DP	59	60		NO	327	146	8
		(40' with wind)			unshielded		SW / DP					1046	35	6
D D	E-47	10 std NO NOZZ	AFFF	300	POOL	30	SK / DP	67	BAD CROS WIND TEST ABORTED					
		at 30 psi					SW/DEDX							
		U2												
	E-48	10 std NO NOZZ	AFFF	300	POOL	30	SK / DP	35	60	30	NO	822	38	11
		at 30 psi					[illegible]					721	217	4
		U2 (0.4375"s")												

E-49	10 std MD NOZZ AFFF at 120 psi UZ	651	POOL	30	SK / DP SK/DEIX	70	60	65	NO	721 822	22 437	5 7
E-50	10 std MD NOZZ AFFF at 120 psi UZ (0.4375"s")	760	POOL	30	SK / DP SK/DEIX	48	60'	16	NO	854 702	58 17	5 6
E-51	10 std MD NOZZ AFFF bored to 3/4" at 30 psi UZ (0.750"s")	880	POOL	30	SK / DP SK/DEIX	60	60	16	NO	699 566	28 41	10 5
F-1	6000 GPM MON. AFFF (150' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	68	67		NO	831 1359	58 27	15 20
F-2	6000 GPM MON. AFFF (150' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	108	65		NO	876 1333	39 15	20 40
F-3	6000 GPM MON. AFFF (90' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	64	70		YES	846 1286	0 12	30 18
F-4	6000 GPM MON. AFFF (50' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	60	60		YES	748 1146	127 35	25 15
F-5	6000 GPM MON. AFFF (25' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	60	62		NO	598 711	63 25	12 30
F-6	6000 GPM MON. AFFF (25' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	60	62		YES	649 1056	75 54	17 15
F-7	6000 GPM MON. AFFF (150' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	62	62		NO	781 1135	102 21	20 9
F-8	6000 GPM MON. AFFF (150' range/30'elevation)	6000	DP crosswind	30	SK / DP SW / DP	61	63		NO	553 1270	89 23	12 10
F-9	6000 GPM MON. AFFF (25' range/30' elevation)	6000	DP crosswind	30	SK / DP SW / DP	61	62		NO	576 1059	101 44	35 9
F-10	6000 GPM MON. AFFF (150' range/20' elevation)	6000	DP crosswind	30	SK / DP SW / DP	63	64		NO	461 1230	104 55	12 14
F-11	6000 GPM MON. AFFF (25' range/20' elevation)	6000	DP crosswind	30	SK / DP SW / DP	56	60		NO	671 1138	25 49	60 27
F-12	6000 GPM MON. AFFF (25' range/15' elevation)	6000	DP crosswind	30	SK / DP SW / DP	61	62		YES	869 1005	0 22	40 14
F-13	6000 GPM MON. AFFF (150' range/15' elevation)	6000	DP crosswind	30	SK / DP SW / DP	61	61		NO	765 1022	98 89	30 6
F-14	6000 GPM MON. AFFF (180' range/15' elevation) (60 deg. in wind)	6000	DP	30	SK / DP SW / DP	78	54		NO	913 1005	275 352	NO NO
F-15	6000 GPM MON. AFFF (140' range/15' elevation) (60 deg. in wind)	6000	DP	30	SK / DP SW / DP	62	65		YES	662 958	190 50	13 6

F-16	6000 GPM MON.	AFFF	6000	DP	30	SK/WING	60	63	YES	539	109	18
	(140' range/30' elevation) (60 deg. in wind)					SW / DP				824	132	14
F-17	6000 GPM MON.	AFFF	6000	DP	30	SK/WING	60	63	YES	611	4	55
	(45' range/30' elevation) (60 deg. in wind)					SW / DP				886	96	30
G-1	6 WD NOZZLES	AFFF	30/NOZ	DP	30	SK / DP		60	NO	872	0	15
	TYPE S/30 psi (no upwind wall)					SW / DP				735	200	NO
G-2	6 WD NOZZLES	AFFF	60/NOZ	DP	30	SK / DP		60	NO	208	0	30
	TYPE S/100 psi (no upwind wall)					SW / DP				618	0	15
G-3	6 WD NOZZLES	AFFF	60/NOZ	DP	30	SK / DP		60	NO	254	117	2
	TYPE S/bored to 0.625" (no upwind wall)					SW / DP				603	57	22
G-4	6 WD NOZZLES	AFFF	90/NOZ	DP	30	SK / DP		60	NO	257	3	30
	"S"/bored 0.625 (57 psi) (no upwind wall)					SW / DP				580	0	2
G-5	6 WD NOZZLES	AFFF	90/NOZ	DP	30	SK / DP		60	NO	200	211	3
	"S"/bored 0.625 (57 psi) (no upwind wall)					SW / DP				763	27	15
G-6	6 WD NOZZLES	AFFF	90/NOZ	DP	30	SK / DP		60	NO	344	78	3
	"S"/bored 0.625 (57 psi) (no upwind wall)					SW / DP				912	26	25
G-7	6 WD NOZZLES	AFFF	90/NOZ	DP	30	SK / DP		60	YES	651	0	30
	"S"/bored 0.625 (57 psi) (no upwind wall)					SW / DP				506	0	2
G-8	6 WD NOZZLES	AFFF	90/NOZ	DP	30	SK / DP		60	NO	892	106	0
	"S"/bored 0.625 (57 psi) (no upwind wall)					SW / DP				314	0	25
G-9	1 1/2" H/LINE	AFFF	100	DP	30	SK / DP			64	235	57	NO
	MIL SPEC NOZZLE (no up/dn wind wall,debris)					SW / DP				608	23	15
G-10	SMALL ROBOT	AFFF	450	DP	0	SK / DP			52	N O	D A	T A
	450 GPM MON. (no up/dn wind wall)					SW / DP				631	43	35
G-11	SMALL ROBOT	AFFF	450	DP	30	SK / DP			70	294	533	3
	(no up/dn wind wall)					SW / DP				502	10	35
G-12	SMALL ROBOT	AFFF	450	DP	30	SK / DP			180	188	93	4
	70' from unshield side (unshielded upwind)					SW / DP				1146	4	
G-13	SMALL ROBOT	AFFF	450	DP	30	SK / DP			NO	907	212	8
	60 deg. into wind (unshielded downwind)					SW / DP				1200	111	10
G-14	SMALL ROBOT	AFFF	450	DP	30	SK / DP			YES	801	208	NO
	60 deg. into wind (unshielded downwind)					SW / DP				1140	78	NO
G-15	WHEELED SHIELD	AFFF	250	DP	30	SK / DP			37	904	164	10
	ST bore 15/16 NOZ					SW / DP			reflash	1289	15	16
G-16	2 1/2" H/LINE	AFFF	250	DP	30	SK / DP			50	798	109	7
	hose control/50' std. off (unshielded upwind)					SW / DP				1092	125	12
G-17	2 1/2" H/LINE	AFFF	250	DP	0	SK / DP			60	765	69	8
	hose control/port. shield					SW / DP				991	60	12

G-18	1 1/2" H/LINE	AFFF	125	DP	30	SK / DP			160	643	160	8
	hose control/50' std. off			(unshielded upwind)		SW / DP				765	102	13
G-19	1 1/2"-2 1/2"	AFFF	375	DP	30	SK / DP			160	925	195	6
	H/LINES w/hose control					SW / DP				1082	120	15
G-20	6 WD NOZZLES	AFFF	60/NOZ	DP	30	SK / DP			NO	594	723	7
	"S"/bored 0.625 (30psi)			(no upwind wall)		SW / DP				611	64	25
G-21	6 WD NOZZLES	AFFF	60/NOZ	DP	30	SK / DP			NO	594	83	9
	"S"/70 psi			(no upwind wall)		SW / DP				616	59	13
H-1	P16 HALON	1211	5 pps	DP	30	SK / DP	85	150	NO	986	244	NO
				(no front wall)		SW / DP		1211 EMPTY		333	63	NO
H-2	P16 HALON	1211	5 pps	DP	30	SK / DP	70	150	NO	788	275	17
	30' from upwind			(no front wall)		SW / DP				263	72	13
H-3	P16 TURRET	AFFF	240	DP	30	SK / DP	60	115	YES	622	76	40
	w/lock dev.			(no front wall)		SW / DP			120	301	14	15
	H/LINE in hose cont.		60				90HL					
	NURSED						115N					
H-4	P16 TURRET	AFFF	240	DP	30	SK / DP	73	114	YES	703	71	30
	w/lock dev.			(no front wall)		SW / DP			120	357	24	20
	H/LINE in hose cont.		60				91HL					
	NURSED						114N					
H-5	P16 TURRET	AFFF	175	DP	30	SK / DP	62	110	YES	612	64	40
	w/lock dev.			(no front wall)		SW / DP			91	453	106	40
	H/LINE in hose cont.		60				84HL					
	NURSED						110N					
H-6	P16 TURRET	AFFF	60	DP	30	SK / DP	78	90	YES	811	126	10
	w/lock dev.					SW / DP			145	610	55	15
	H/LINE in hose cont.						90HL					
H-7	P16 TAU HALON	1211	5 pps	DP	30	SK / DP	73	91	YES	790	160	8
				(no front wall)		SW / DP			93	452	38	10
H-8	P16 TAU HALON	1211	5 pps	DP	30	SK / DP	66	86	YES	651	314	10
				(no front wall)		SW / DP			107	456	62	5
H-9	P16 TURRET	AFFF	175	DP	30	SK / DP	60	86	NO	602	260	
	w/lock dev.			unshielded		SW / DP				468	69	8
	(crosswind attack)											
H-10	P16 TURRET	AFFF	240	POOL/DP	30	SK/WING	[illegible]	95	YES	561	320	15
	w/HANDLINE	AFFF	60			SW / DP	90HL		135	691	80	10

APPENDIX B

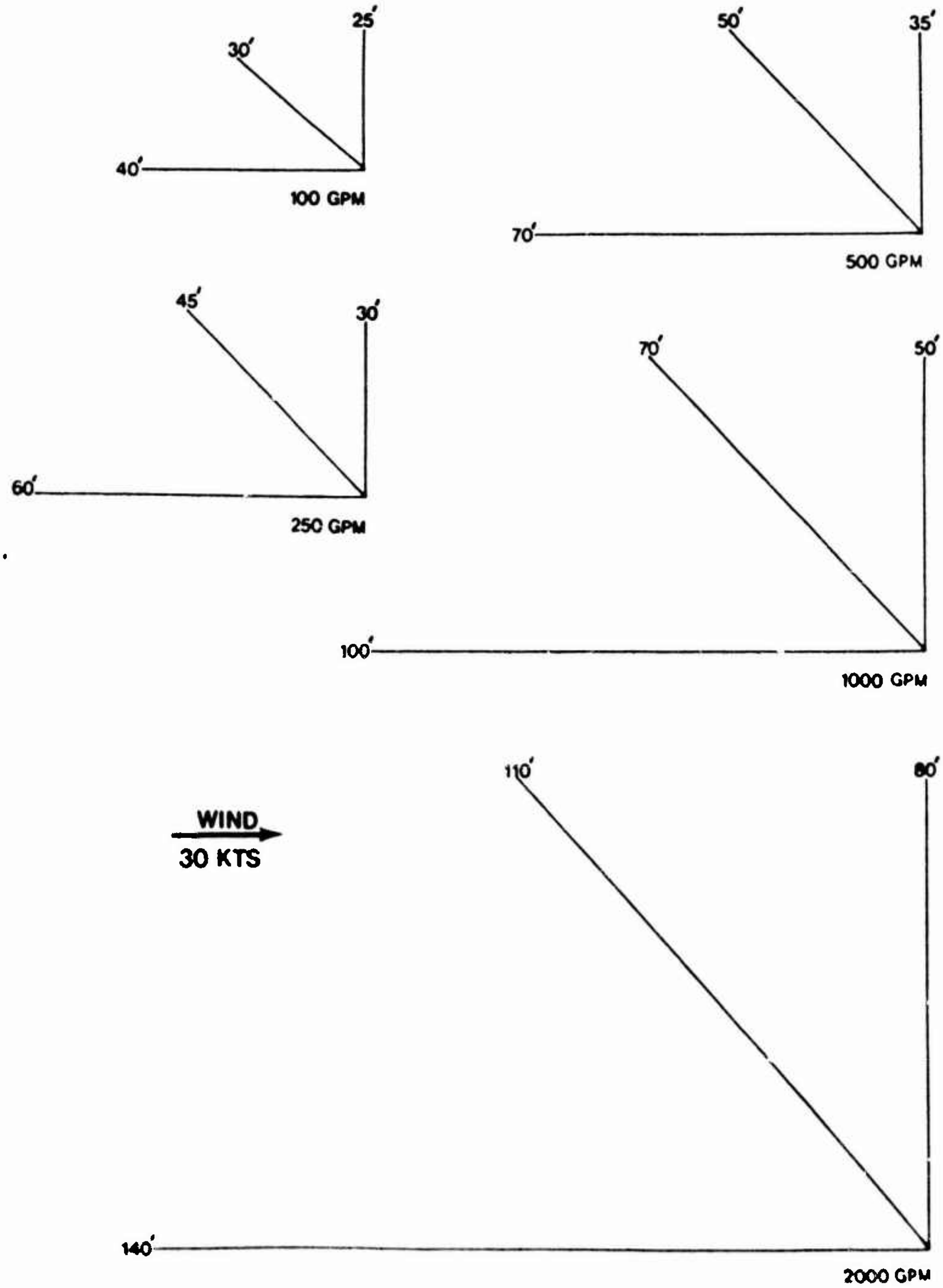
STREAM REACH DATA

(GPM) FLOW	MONITOR	NOZZLE	NOZZLE SETTING	(PSI) N.P.	ELEV ANGLE	TEST NUMBER	(Kt) WIND SPEED	DISCHARGE ANGLE W/R TO WIND DIRECTION: WITH	INTO	CROSS	10	30	60	COMMENTS
000	3" Stang	2 1/2"	S.S.	115	0°	4	30			65'		70'	100'	
000	3" Stang	2 1/2"	S.S.	120	0°	15	30		180'	100'		95'	100'	
020	3" Stang	2 1/2"	S.S.	80	0°		30		98'	95'		95'	93'	
					10°		30		140'				116'	
300	3" Stang	2 1/2"	S.S.	115	0°	24	0	235'						
					30°			265'						
300	4" Stang	2 1/2"	S.S.	150	0°	40	0	110'						
					10°			280'						rain
					20°			380'						entire
					30°			350'						length
400	4" Stang	3 1/4"	S.S.	60	0°	41	0	100'						
					10°			220'						
					20°			340'						400'-340' rain
					30°			320'						200'-370' rain
600	3" Stang	2 1/2"	S.S.	200	0°	20	30			100'		90'	90'	
600	3" Stang	2 1/2"	S.S.	200	0°	36	30			80'		130'		*
					30°			330'		*250'				*broken out of wind
900	3" Stang	2 1/2"	S.S.	200	0°	22	0	255'						
					30°			385'						
700	8" Stang	4"	S.S.	100	0°	46	0	130'						
					10°			260'						240'-260' rain
					20°			360'						330'-360' rain
					30°			425'						365'-425' rain
					36°			400'						350'-400' rain
600	8" Stang	4"	S.S.	185	0°	47	0	200'						
					10°			350'						300'-350' rain
					20°			380'						300'-380' rain
					30°			460'						300'-460' rain
					38°			460'						" " "
250	10" Stang	5"	S.S.	220	20°	50	0	370'						310'-370' rain
500	10" Stang	5"	S.S.	230	30°	51	0	545'						360'-545' rain

(GPM) FLOW	MONITOR	NOZZLE	NOZZLE SETTING	(PSI) N.P.	ELEV ANGLE	TEST NUMBER	(Kt) WIND SPEED	DISCHARGE ANGLE W/R TO WIND DIRECTION WITH	INTO	CROSS	10	30	60	COMMENTS
1500	4" Stang	2 1/4"	S.S.	108	0°	42	0	70'						
					10°	42	0	160'						rain entire length
					20°			220'						rain entire length
					30°			250'						200'-250' rain
1500	4" Stang	2 1/4"	S.S.	108	0°	43	0	90'						short streams
					10°			170'						
					20°			230'						rain entire length
					30°			250'						
1500	4" Stang	2 1/4"	S.S.	108	0°	44	0	100'						100'-170' rain
					10°			170'						
					20°			230'						rain entire length
					30°			230'						
1500	4" Stang	2 1/4"	S.S.	108	0°	45	0	80'						
					10°			210'						180'-210' rain
					20°			290'						250'-290' rain
					30°			300'						250'-300' rain
1530	3" Stang	2 1/4"	S.S.	80	0°		30		101'	87'		83'	91'	
					10°		30		140'	123'		108'	103'	
2000	3" Stang	2 1/4"	S.S.	180	0°	21	30			75'		75'	90'	
2000	3" Stang	2 1/4"	S.S.	180	0°	7	0	200'						
					30°			285'						
2000	3" Stang	2 1/2"	S.S.	115	0°	28	30		95'					
					30°				180'			*200'		*part out of wind
					30°	29	30		200'					
2000	3" Stang	2 1/2"	S.S.	110	0°	35	30	160'		100'		90'	100'	*
					30°			310'		130'				
2000	3" Stang	2 1/2"	S.S.	110	0°	39		100'						
					10°			240'						
					20°			340'						260'-340' rain
					30°			340'						250'-340' rain

(GPM) FLOW	MONITOR	NOZZLE	NOZZLE SETTING	(PSI) N.P.	ELEV ANGLE	TEST NUMBER	(Kt) WIND SPEED	DISCHARGE ANGLE W/R TO WIND DIRECTION						COMMENTS
								WITH	INTO	CROSS	10	30	60	
11,000	10" Stang	5"	S.S.	240	10°	49	0	370						310'-370' rain
11,200	10" Stang	5"	S.S.		10°	48	25			190'				*

ESTIMATED EFFECTIVE STREAM REACH AGAINST 30 KNOTS WIND



APPENDIX C

SRI INTERNATIONAL

THERMAL DATA REPORT

October 1982

NIMITZ FIRE TESTS
NWC, Oct. 1982

SUMMARY

The objectives for the SRI International effort were to:

- Document the thermal insult experienced by objects in the fire.
- Determine the heat flux encountered by firefighters outside the flames.
- Monitor the reproducibility of fires where the suppression efforts are to be compared.
- Provide a comparison between the fires of this test series and those of other tests such as the CASS series of 1970.
- Observe environmental effects on the fire characteristics, e.g. wind and debris.
- Determine the effects of suppression efforts on the thermal environment.

Most of the equipment performed satisfactorily throughout the test series and an abundance of data was obtained for 61 of the 63 tests. The 24 channels of data from the 61 tests were grouped into 10 graphs per tests; consequently, the final data package for this test series contain about 600 graphs which support the following conclusions:

- The thermal environment inside the flames at the time suppression was initiated, i.e. peak heat fluxes of 12 to 19 BTU ft^{-2} sec^{-1} and temperatures of 1700 to 2200° was typical of large JP5 pool fires.
- The heat flux external to the fire exhibited intensities and reproducibilities consistent with past experience, e.g., the 1970 CASS tests.
- Wind blown shifts in the flame geometry were a major factor influencing the external thermal field.
- Items on the deck such as the debris pile and the rubber tires introduced considerable scatter in the time to achieve 90% control of the fire because they interfered with getting the agent to the seat of the fire.
- From a fire control standpoint, attacks with AFFF from some nozzles and water from others was less effective than AFFF alone.

NIMITZ FIRE TESTS

NWC, Oct. 1982

1.0 Objectives for the SRI International Effort

- Document the thermal insult experienced by objects in the fire.
- Determine the heat flux encountered by firefighters outside the flames.
- Monitor the reproducibility of fires where the suppression efforts are to be compared.
- Provide a comparison between the fires of this test series and those of other tests such as the CASS series of 1970.
- Observe environmental effects on the fire characteristics, e.g. wind and debris.
- Determine the effects of suppression efforts on the thermal environment.

2.0 Approach and Instrumentation.

Four test variables influence the behavior of the fires and burn durations, (1) fuel arrangement, (2) wind conditions, (3) objects in the fire and (4) suppression efforts. Table 2.0 lists these parameters for the various tests. Figure 2.0 defines the fuel configurations and the type and general location of the objects used in the test fires. For example, fuel configurat[illegible] (1) is a nominal 66'x 60' pool with a measured surface area of [illegible] ft^2 and a combination water and concrete substrate i.e. low spots in the concrete were filled with water to form a fairly level substrate. [illegible]ject configuration (1) equals a shrike motor mounted on the wing of the a[illegible]craft mockup centrally located in the fire.

Table 2.0 lists both the ambient wind and the total air velocity as measured with hand held anamometers just prior to ignition. The total wind values (copied from the NRL data sheets) were measured on the upwind zone of the test deck and were used to provide guidance in adjusting the C-97 aircraft generated wind to the desired velocity. Ambient winds

were monitored adjacent to the recording anamometer station. During the tests, the recording anamometer monitored both the ambient wind velocity and direction. Curves of these parameters are included in the data package for tests up to #40. Unfortunately, strong gusting winds demolished the anamometer prior to test #41 and terminated this monitoring.

Six columns in Table 2.0 describe the fire suppression efforts in terms of the agent used, the application equipment, and the mode of attack. Most of the fires were fought with AFFF or combinations of AFFF and water from the upwind zone deck nozzles (UZ), fire zone deck nozzles (FZ), 1 1/2" hand lines and 2 1/2" hand lines. Fifteen combinations of these agents and equipment are encountered in the table. In Table 2.0 the tests are grouped first according to the fuel configuration and second according to the suppression permutations. All tests that are replications are grouped contiguously and tests that differ in only one parameter are near neighbors. Hopefully this arrangement will expedite the location of tests to be compared.

Table 2.1 lists the parameters monitored during the tests, the instrumentation involved and the identification of each sensor. Figure 2.1 shows the location of each instrument with respect to the fire bed and the trailer that housed the data acquisition system. Most of these sensors are the same type if not the same device used in the CASS tests of 1970. For example, three of the four radiometer types were used in the CASS tests and the Beckman Whitney radiometers are the same instruments. Only the Moffett radiometer and the pneumatic load were not of a type used in the previous tests. Figure 2.2 shows the arrangement and principle of operation for the Moffett radiometer and the pneumatic load cell. All the other sensors including their self contained cooling systems and thermal protection are described in Reference 1.* Radiometers R1, R2, R3, R4 and thermocouples TC1, 2, and 3 were mounted on the end of an insulated and water cooled pipe that cantaleavered 10' into the fire from the edge of the concrete deck as illustrated in figure 2.3. When suppression commenced, the pipe was retracted on an overhead rail so that the instruments would not interfere with the suppression efforts. All the radiometers were calibrated as described in Reference 1. However, a small field radient

*NOLTR 73-87.

source, i.e. a catalytic propane burner was used to check the performance of the radiometers exposed to the flames.

All of the Hy-cal and Honneywell radiometers outside the flames were equipped with windows to prevent convective cooling by the ambient winds. Sapphire windows were used on R5, R6, and R7 and R8 though R12 were behind saran plastic wrap. Because of the spectral characteristics of the window absorption, we measured this loss during the min sump burn by observing the signal reduction when each type of window was inserted in front of the thermopile in the telescopic radiometer. This loss amounted to about 5% for the saran and 20% for the sapphire. By the time the sump could be burned, a large number of the thermal flux vs. time curves for the carrier deck fire tests had been plotted in final form consequently to avoid confusion. All the curves were plotted without the window absoroption correction. Considering the fluctuating nature of the signals, the saran correction is of negligible consequence and the sapphire loss is probably less than the effect of the soot that collected on the windows of those close in radiometer during many of the fires. An allowance for the window loss has been included in the flux vs. distance curves attached to this report.

All data except for the pneumatic load cells were recorded on a Hewlett-Packard 3052A data acquisition system located in the instrument trailer. This system scans the 24 channels of information in about three seconds and records the raw data in digital form on magnetic tape. After the tests, the HP 3052A converts the data to appropriate units for plotting the desired parameter as a function of time from ignition. Because all events observed during one scan are plotted at the same time, there is a three second uncertainty with respect to the ignition time in addition to the human jitter in pushing the start button when the ignition torch was observed to ignite the fuel. All channels included a R. C. circuit with a one second time constant to smooth out the high frequency fluctuations and recover a larger fraction of the available information than would be obtained with instanteous sampling.

Signals from the pneumatic bubblers were recorded in analogue form on H.P. strip chart recorders so that a visual record was always available to guide the operator in adjusting the nitrogen pressures.

3.0 Results

3.1 Performance of Equipment

Most of the equipment performed satisfactorily throughout the test series and an abundance of data was obtained for 61 of the 63 tests. The 24 channels of data from the 61 tests were grouped into 10 graphs per tests, consequently the final data package for this test series contain about 600 graphs.*

Unfortunately three items kept the operation from achieving a perfect performance. First, cockpit trouble with the computer let all the data from tests 13 and 27R escape. Second, the nitrogen flow vs. pressure characteristics of the Moffett radiometer system changed during the series; consequently, despite repeated recalibrations with the propane torch, the data from these two radiometers is not very reliable. Third, the time lapse camera stationed under the C-97 recorded the test slates perfectly but missed all of the fires.

3.2 Thermal Threat in the Fire

Table 3.0 summarizes the peak temperature and heat flux values encountered by the sensors in the fire before the probe was withdrawn at the onset of suppression, i.e. about 30 sec. after ignition. During this

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*Pertinent test information such as the locations of the radiometers and the type and times of suppression activities are indicated in the legend on each graph. Also the suppression events have been marked on the time axis for some of the radiometer curves, i.e. R5 through R11 and R16. The convention followed in marking the time axis is tick marks below the axis accompanied by the indicator for the application equipment indicates starting times and similar marks above the axis signify termination. Throughout the data package and these comments, the abbreviations have the following meanings: A = AFFF, W = water, C = control time, i.e. 90% extinguished and E = time extinguished.

short preburn, the fire is in a period of rapid transient buildup; consequently, average values of the heat flux have little meaning under these condition. However, the telescopic radiometer remained focused on the mock up aircraft tail throughout the test so that it observed both the transient buildup and the perturbations during the fire suppression activities. When the time of the peak is indicated in brackets, it indicates the peak temperature was recorded during the fire suppression.

Two features of the data are of interest: (1) the magnitudes of the fluxes and temperatures and (2) their variations with respect to the experimental valuables. First, the magnitudes are characteristic of values that have been observed in other JP5 fires. Most of the temperatures measured by the thermocouples are in the range from 1200 to 2000°F customarily observed in hydrocarbon pool fires; however, about 70% of the peak values were below 1500°F which corresponds to the cooler part of the fire. Also about 70% of the T.C.1 reading were less than the T.C.3 peak values suggesting that the closer proximity of T.C.1 to the steel housing for the radiometers may be related to the cooler temperatures. R16, the telescopic pyrometer frequently recorded peak temperatures above 2000° and occasionally reached 2200°F. Similar temperatures were observed in a recent series of JP5 flowing fuel pool fires on the NASA Las Cruces simulated aircraft carrier deck. For comparison, Table 3.1 lists values from some NASA fire measurements with thermocouples and bare radiometers mounted on a probe in the fire.

In principle, R2 and R4 were supposed to measure the radiation component of the thermal flux; however, the erratic performance of these sensors engenders little faith in the results. Values in the 50 to 70% range may be reasonable but the much higher and lower values are suspect.

Second, the search for a correlation between the thermal insult and the experimental parameters lead beyond the conditions listed in Table 2.0 to visual observations and photographs of the fire behavior during the preburn period. Test 10 is a prime example of how the fire development from ignition to full involvement can influence the observed thermal flux and temperatures. Tests 7 through 11 were conducted on the

same day and involved the same fuel and object configuration. Also, the forced wind velocities were reasonably constant for tests 8 through 11. However, the ambient wind shifted during test 10 and retarded the flame spread across the pool surface. In fact, suppression was commenced before the pool was completely involved under the instrument probe; consequently, the observed values correspond to the environment at the edge of a fire. The curves for R5, R6 and R7 provide a good check on the promptness and uniformity of the transition from ignition to full involvement.

3.3 Thermal Flux Encountered by Firefighters and Others Outside the Flames

Typically we plot the thermal radiation field in two ways, first as a function of time to emphasize factors associated with fire size and burning rate, e.g. flame spread across the pool and fire extinguishment, and second, as a function of position to indicate the symmetry of the fire plume. The more distant radiometers, e.g. R9 through R15 provide a better average indication of the total fire radiation because the view factor is about equal from all parts of the flames on their side of the fire. Consequently, these radiometer traces are suitable for monitoring the effect of test parameters on the general field intensity and the impact of suppression tactics on flame extinguishment. Conversely radiometers R5, R6, and R7 are more sensitive to assymetrics in the flame geometry such as those caused by the wind. Finally, R10 and R12 indicate the field at comparable distances but along axis spaced by 90°. We now examine the radiation field data for evidence regarding various conclusions reached by test personnel based on visual observation.

- Fighting fires into the wind (~ 15 KTS) with hand lines is almost impossible. Test 35 was conducted without forced ventilation but with an ambient wind of about 15 KTS blowing toward the upwind deck from which the attack with band lines was launched. During this exercise, the firemen were forced to retreat because of the excessive thermal insult. Table 20 lists 7 tests along with #35 where the fire was fought with a combination of 1 1/2 and 2 1/2 inch hand lines. It should be noted that in test 35, the FZ system was activated as an emergency measure only after the firemen were forced to retreat. A comparison of the curves for R10 and R12 shows the abnormally high radiation field in the UZ area caused by the wind blown

flames. If the peak thermal fluxes for the 8 similar tests are compared at the R10 and R12 positions (see table 3.2), the wind effect becomes very apparent. For human skin exposed to thermal radiation, the pain threshold is about 0.4 BTU $ft^{-2}sec^{-1}$ and the ignition threshold for cellulosic materials such as paper and cotton fabrics is about 1.5 BTU $ft^{-2}sec^{-1}$ for fractional minute exposures. Figure 2.0 shows these pains and ignition thresholds on a plot of the heat flux intensity vs. distance from the fire for various tests including a shaded band that includes seven tests from the Nov. 1970 CASS tests. During test 35 the flux at the R12 position was almost twice the normal value to be expected of that distance. Because the suppression activities precluded closer radiometers on the S-W end of the fire, we have no direct data of the firefighters positions; however, an extrapolation along a view factor curve as shown in Figure 2.0 leads to thermal insults near the ignition threshold at the firemen attack position. Along the string of radiometers at 90° (the * in figure 2.0), the thermal flux was not particularly intense, indicating that the fire intensity was normal, only the flame geometry was rearranged by the wind.

- With a clean deck and AFFF coming from both the upwind (UZ) and Fire Zone (FZ) nozzles, the fires were controlled very quickly, e.g. about 30 sec. Tests 1R, 6, and 30 support this point. In all these cases, the radiometer readings have dropped dramatically before the recorded control times which ranged from 20 to 40 min.

- AFFF from the upwind zone (UZ) makes a major contribution to fire suppression when both UZ and FZ nozzles are spraying AFFF. If water is substituted for the AFFF in the UZ nozzles, the extinguishing action of the UZ-FZ combination is hampered as much if not more than when the UZ nozzles are secured. According to table 2.0, tests 1, 1R and 6 provide the base line data for AFFF applied from both zone nozzles on a nearly clean deck. The radiometer curves for these tests support the control times of 24 to 30 sec listed in table 2.0. Substituting water in UZ, tests 3, 3R and 7, tripled the control time in the first two cases but increased it only about 50% in test 7. A comparison of test 2 against tests 3 and 3R indicates the effect of UZ secured vs. UZ spraying water. The radiometer curves show a quicker knockdown without the water; however, the control times were long in both cases and 1 1/2" hand lines were brought in after the first 90 to 120 seconds to assist extinguishment.

  Another comparison of the effects of mixing AFFF and water occurred when the 2 1/2" hand line was used to cool the ordnance with water while the 1 1/2" hand line was used to

extinguish the fire with AFFF. A comparison of the control times shown plotted in Figure 3.1 shows considerable scatter in the control times but while the water effect was not as pronounced as in the UZW-FZA combination, the control times with AFFF in both lines were generally shorter than when water was used in the 2 1/2" line.

- Debris on the deck can change the geometry of the fire and effect the extinguishing capabilities of the wash down system. A comparison of tests 1, 1R, and 6 vs. 30 or tests 20 and 21 vs. 25, 25R, 26 and 55 show the main effect is scatter in the time to control the fire, i.e. sometimes control with debris was as fast as with a clear deck but usually more time was required (both with object arrangement 2 and when tires were added to configuration 1). Figure 3.1 shows this scattering of control times and a tendency for longer control times.

- Reproducibility: One of the objectives in monitoring the thermal radiation field was to check the reproducibility of the thermal insult at the onset of suppression. According to Table 2.0, tests 1 and 1R constitute a replication. In Figure 3.0 their curves are almost identical; in fact, they are too similar. Variations of ± 20% are very common in outdoor pool fire reproducibility as indicated by other curves in Figure 3.0 for the same general fire conditions, e.g. tests 10, 11, and 15. Long term reproduciblity is about the same as the short term case as indicated by the shaded band in Figure 3.0 which as previously mentioned is for the CASS tests of 1970.

4.0 Conclusions

- The thermal environment inside the flames at the time suppression was initiated, i.e. peak heat fluxes of 12 to 19 BTU $ft^{-2}sec^{-1}$ and temperatures of 1700 to 2200° was typical of large JP5 pool fires.

- The heat flux external to the fire exhibited intensities and reproducibilities consistent with past experience, e.g. the 1970 CASS tests.

- Wind blown shifts in the flame geometry were a major factor influencing the external thermal field.

- Items on the deck such as the debris pile and the rubber tires introduced considerable scatter in the time to achieve 90% control of the fire because they interfered with getting the agent to the seat of the fire.

- From a fire control standpoint, attacks with AFFF from some nozzles and water from others was less effective than AFFF alone.

TABLE 2.0

TEST PARAMETERS, FUEL PATTERN, OBJECTS IN FIRE, WIND & AGENT

Patterns		Wind		Agent Type				Agent On Time, Sec.						
Fuel	Obj.	Total Kts.	Ambient Kts.	UZ	FZ	1½"	2½"	UZ	FZ	1½"	2½"	Control Time Sec.	Comments	Test
1	1	35	3.5			A				48		37		12
1	1	30	0.4-1.5			A				32		27	(5)	12R
1	1	25-30	1.5-1.6			A				47		49		13
1	1	30	2.7-3.5				A				41	27		8
1	1	30	1.2-1.5				A				40	42		14
1	1	30	16-23.4				A				51	21		36
1	1	30	0			A	A			35	35	20		9
1	1	30-35	0.3-1.1			A	A			50	50	13		9R
1	1	25-30	5-9.9			A	A			75	75	35	(2)	10
1	1	30	4.5-8.5			A	A			61	65	115	(1)	11
1	1	35	1.5-2.4			A	A			33	33	25		17
1	1	30	3.5-5.2			A	A			38	38	30	(3, 4)	18
1	1	35	2.7-5.1			A	A			47	47	18	(4)	24
1	1	0	2.5-4.9		A	A	A		90	35	-	135		35
1	1	30	1.7-3.1			A	W			37	37	26	(4)	15
1	1	30	1.9-4.1			A	W			33	33	39	(3)	16
1	1	30	2.5-3.7			A	W			43	43	38	(3, 4)	23
1	1	30	.3-1.1				AW				40-47	30		37
1	1	30-35	1.5-3.1	A	A			42	34			24		1R
1	1	11-15	3.2-4.1	A	A			40	42			30		6
1	1	35	—		A	A			42	124		100		2
1	1	35-40	0-1.1	A	A	A		37	37	77		25		1
1	4	30	6.9-11.4	A	A	A		41	41	161		140		38
1	4	30	9.6-13.5	A	A	A		38	38	93		24		39
1	1	30	4-12.8	W	A	A		63	57	130		250		3
1	1	30	0-0.4	W	A	A		55	55	90		90		3R
1	4	35	6.3-10.9	W	A	A		53	46	156		80		40
1	1	11-19	1.7-3.5	W	A	A		43	43	123		45		7
1	1	30-35	0.3-3.1	W	W	A		42	42	135		130		4
1	1	12-20	3.5-5.9	W	W	A		45	45	112		113		5
1	1	30	1.7-2.0	A	A	A	A	37	37	45	44	18	(4)	20
1	1	15-20	1.5-1.8	A	A	A	A	32	32	43	43	23	(4)	21
1	1	30	0.3-1.4	W	A	A	W	32	32	40	39	33	(3, 4)	19
1	1	15	1.8-2.7	W	A	A	W	33	33	44	44	29	(4)	22
1	2	30-35	2.6-3.7	A	A			40	40			40		30
1	2	30	3.5-6.0	A		A		64		159		100		53
1	2	30	4.6-6.1	W	A	A		60	53	—		85		52
2	2	30-35	2.1-3.1			A	A			58	58	22		28
2	2	0	3.5-5.0			A	A			46	46	52		29
2	2	30	0.3-1.0	A	A	A	A	43	43	50	50	20		25
2	2	35	3.5-4.1	A	A	A	A	39	37	46	46	22		25R
2	2	15	2.1-3.6	A	A	A	A	72	72	80	80	39		26
2	2	30	1.1-2.3	A	A	A	A	34	36	69	69	40		55
2	2	30-35	0-1.1	W	A	A	W	61	61	69	68	46		27
2	2	30-35	3.5-4.0	W	A	A	W	57	57	67	66	60		27R
2	2	35	0-1.1	W	A	A	W	38	38	40	40	40		27R1
2	2	30	—	W	A	A	W	121	121	253	—	195	(6)	56
2	2	30	1.7-3.1	W	A	A		49	49	212		190		54

TABLE 2.0 CONT.

Patterns: Fuel	Patterns: Obj.	Wind: Total kts.	Wind: Ambient kts	Agent Type: UZ	Agent Type: FZ	Agent Type: 1½"	Agent Type: 2½"	Agent On Time, Sec.: UZ	Agent On Time, Sec.: FZ	Agent On Time, Sec.: 1½"	Agent On Time, Sec.: 2½"	Control Time Sec	Comments	Test
3	3	20	1.1 - 3.1				A				49	5		32
3	3	20 - 25	2.1 - 3.6				A				-	4		33
3	3	20	0 - 1.1				W				43	E = 130		31
3	3	10	3.5 - 4.7				W				51	E = 90		34
3	3	N.A.	19.3 - 22.5			A				43			(9)	44
4	5	N.A.	6.9 - 11.4									E = 45	(8)	45
4	5	N.A.	13 - 22.8			A				16 S / 21 P		E = 31	(10)	46
4	5	N.A.	16.1 - 21.6										(11, 12)	47
4	5	N.A.	12.6 - 18.9										(11, 12)	48
4	5	N.A.	1 - 3.2										(11, 12)	49
4	5	N.A.	0 - 1									E = 45	(11)	50
4	5	N.A.	0.5 - 1.8									E = 62	(11)	51
5	5	N.A.	15.3 - 21			A	A						(8)	41
5	5	N.A.	10.6 - 14.8			A	A						(8)	42
5	5	N.A.	16.3 - 21			A							(7)	43

Fuel Patterns - See Figure 2.0

1 = 1200 to 1500 gal JP5 pool
2 = 1200 gal pool + ~ 50 GPM running fuel in debris
3 = ~ 100 gal JP5 pool (14'x 14'x 8"), JP5
4 = 40 to 100 GPM running fuel in debris, JP5
5 = 40 to 100 GPM running fuel in debris, JP4

Objects in Fire

1 = Aircraft mock-up and shrike motor
2 = Aircraft mock-up and shrike motor + sidewinder motor in debris pile
3 = Shrike motor on deck
4 = Aircraft mock-up and shrike motor + rubber tires
5 = Sidewinder motor in debris pile

Comments

1 = Wind reversed from normal direction
2 = Difficult ambient wind
3 = Hnad lines stand back 50'
4 = 1 1/2" line extinguishing fire, 2 1/2" line cooling ordnance
5 = Aggressive extinguishment
6 = Four nozzles plugged
7 = PKP from MB5
8 = TAU unit supplying agent
9 = Two 30 lb PKP and a 17 lb Halon 1211 extinguishers
10 = Two handlines S = Starboard, P = Port
11 = AFFF supplied by monitor
12 = Fire not extinguished

Table 2.1

MEASURED TEST PARAMETERS & INSTRUMENTATION

Parameter	Instrumentation	Designation	Window
1. Thermal Insult Inside Fire			
• Total thermal flux	Hy-Cal Radiometers	R1, R2	Bare
• Radiation thermal flux	Moffett Radiometers	R2,R4	Bare
• Gas temperatures	Chromal-Alumal thermocouples	T.C. 1,2,3	Bare
• Flame temperatures	Telescopic pyrometer	R16	Bare
2. Thermal Insult Outside Fire			
• Total thermal flux, near	Hy-Cal radiometers	R5,R6,R7,R8	Sapphire saran
• Total thermal flux, far	Honeywell thermopiles	R9,R10,R11,R12	Saran
• Total thermal flux, far	Beckman-Whitney radiometers	R13,R14,R15	Air screen
• Fire size	Super 8 mm time lapse camera	C1,C2	
3. Ambient Conditions			
• Wind	Propeller anamometer		
• Air temperature	Dry bulb thermometer		
• Humidity	Wet bulb thermometer		
4. Burning Rate	Pneumatic load cell		

TABLE 3.0

PEAK HEAT FLUXES & TEMPERATURES MEASURED IN THE FIRE

				BTU FT^{-2} SEC^{-1}				F°			
TEST #	FUEL	OBJ	TOTAL WIND KTS.	R1	R2	R3	R4	T.C. 1	T.C. 3	R16	R16 Peak Time sec
1	1	1	35-40	16.3		13.6		1320	1630	2080	26
2	1	1	35	14.7		12.6		1020	850	2040	32
3	1	1	30	12.2		11.7		1140	1310	2260	(110)
3R	1	1	30	14.6	10	12.7		1200	1600	2010	60
4	1	1	30-35	17.		14.1		1480	1920	2110	(155)
5	1	1	12-20	18.5	8.4	13	13	1520	1740	2290	(150)
6	1	1	11-15	17.5	9	18.1	13.5	1690	1960		
7	1	1	11-19	18.1	11.5	19.3		1800	1990	1960	(58)
8	1	1	30	17.5	13.2	17.6	17.6	1720	1950	2010	(66)
9	1	1	30	18.7	6.7	17.4	15.1	1900	1900	1900	(42)
9R	1	1	30-35	15.5		15.8		1640	1780	2260	(57)
10	1	1	25-30	9.3	4.2	5.1		790	480	2240	70
11	1	1	30		11.2	19.7	16.2	1870	1870	2310	55
12	1	1	35			15.4	8.2	1510	1730		
12R	1	1	30		6.3	11.8	13.7	1420	1060	1420	17
14	1	1	30	12.6	6.7	17.2	17.8	1940	1750		
15	1	1	30	15.1	6.3	14.5	14.5	1620	1910	1820	20
16	1	1	30	13.4	5.0	13	11.3	1360	1690	1770	20
17	1	1	35		4.4	10.4	12.3	1300	1100	1500	12
18	1	1	30		4.8	9.7	9.2	1300	1000	2040	25
19	1	1	30	15.2	6.2	16.6		1500	1750	1910	20
0	1	1	30	18.7		18.7		1900	2010	1590	12
21	1	1	15-20	16.4	6.3	17.8		1590	2100	1870	13
22	1	1	15	16.2	8.	16.9		1610	1920	1910	22
23	1	1	30	12.7	8.9	12.3		1250	1570	1670	35
24	1	1	35	16.3	8.6	16.7		1760	176[illegible]	1870	35
25	2	2	30		11	11.4		1210	1400	1540	23
26	2	2	15		1.6	20		315	166	1070	75
27	2	2	30-35	15.2	16.3	13.7		1520	1740	2000	(70)
28	2	2	30-35	13.1		14.1		1160	1510	2080	(65)
29	2	2	0	7.0	8.1	5.7		940	960	2000	(85)
30	1	2	30-35	11.6	9.6	8.3		940	1130	1896	(50)
25R	2	2	35	15.6		13.7		1660	1720	2000	(53)
1R	1	1	30-35	18.3	16.6	14.1		1520	1710		
35	1	1	0	16.4		18.5		1830	1960	1870	8
36	1	1	30	12.8		14.3		1380	1630	1770	30
37	1	1	30	11		11.6		1140	1330	1930	15
38	1	4	30	10.8		8.6		860	1040	1450	20
39	1	4	30	14.4		14.2		1610	1740	1390	25
40	1	4	35	17.6		18		1710	1710	1600	45
52	1	2	30	15.4		17.6		1530	1820	2050	97
53	1	2	30	15.6		16.9		1640	1790	2060	(60)
54	2	2	30	4.4		2.8		196	455	2250	(220)
55	2	2	30	11.7		11.7		1060	1280	1970	(65)
56	2	2	30	11.6		11.3		1300	1360	2190	(220)
27R	2	2	30-35								
27R1	2	2	35	16.		15.4		1540	1670	1850	(50)

TABLE 3.1

SUMMARY OF TEST CONDITIONS & RESULTS FOR SPILLING FUEL FIRES

			Test No. 1	2	3	4	5	6	7
TEST CONDITIONS									
Fuel Spill Rate		GPM	300	600	300	330	570	570	150
Total Fuel		GAL.	600	900	525	990	998	998	90[illegible]
Spill Duration		min.	2	1.5	1.75	3	1.75	1.75	6
Wind		mph	30	4.7	24	15	18	18	18
TEST RESULTS									
† Time to Max Area		min.	1.5 to 2.5	1.5 to 1.8	1.2 to 1.5	1.7 to 2.2	2 to 5	1.5 to 2.7	1 to 2
† Flame Tilt From Vertical		DEG.	62 to 66	0 to 15	60	58	54	20 to 45	37
Total Burn Time		min.	7.0	5.5	4.75	7	12.75	6.5	14.5
Post Spill Burn Time		min.	5	4	3	4	11	4.75	8.5
POSITION A									
Temp. 330	Max	°F	2200	2230	2250	2250	2110	2150	2240
" "	Avg.	"	2070	2100	2150	2180	1990	2050	2130
ΔT		"	300	300	200	200	200 to 600	100 to 1000	150
Cal 328	Max.	BTU Ft^{-2} Sec^{-1}	20 *	25.4	29	21.5	13.4	12.5	21.2
" "	Avg.	"	16	20	25	20	6.8	10	15
ΔR		"	5 to 9	6 to 14	4 to 8	3 to 5	8 to 12	5 to 9	2 to 5
Rad 329	Max.	"	21	27	26.4	19	12.5	14	11.8
" "	Avg.	"	16.5	22.8	23.2	17.5	7	10	10
ΔR		"	5 to 9	5 to 14	3 to 10	2 to 12	5 to 12	6 to 11	2
POSITION B									
Temp. 333	Max.	°F	2150		1840	1450	1490	750	480
" "	Avg.	"	1500		1500	1150	1080	650	390
ΔT		"	400 to 800		500 to 1000	200 to 700	100 to 600	100	100
Rad 331	Max.	BTU Ft^{-2} Sec^{-1}	25.8 *		16.5	12.5	10.3	6 & 14.3	7.5 & 13
" "	Avg.	"	15		12.5	6.8	6	3.5 & 7	4
ΔR		"	8 to 18		7 to 11	7 to 12	2 to 7	3 to 12	3 to 7
Cal 332	Max.	"	25 (sec)		11.5	7.5	7	5	2.7
" "	Avg.	"	15		7.5	4.8	4	3	2
ΔR		"	8 to 14		2 to 6	3 to 6	1 to 2	100	100

Table 3.2

WIND GENERATED FIRE ASSEMETRY (Test 35)

Test #	R12	R10
	BTU Ft^{-2} Sec^{-1}	
9	.148	.111
9R	.172	.171
10	.292	.257
11	.278	.222
17	.147	.132
18	.146	.21
24	.166	.162
35	.48	.15

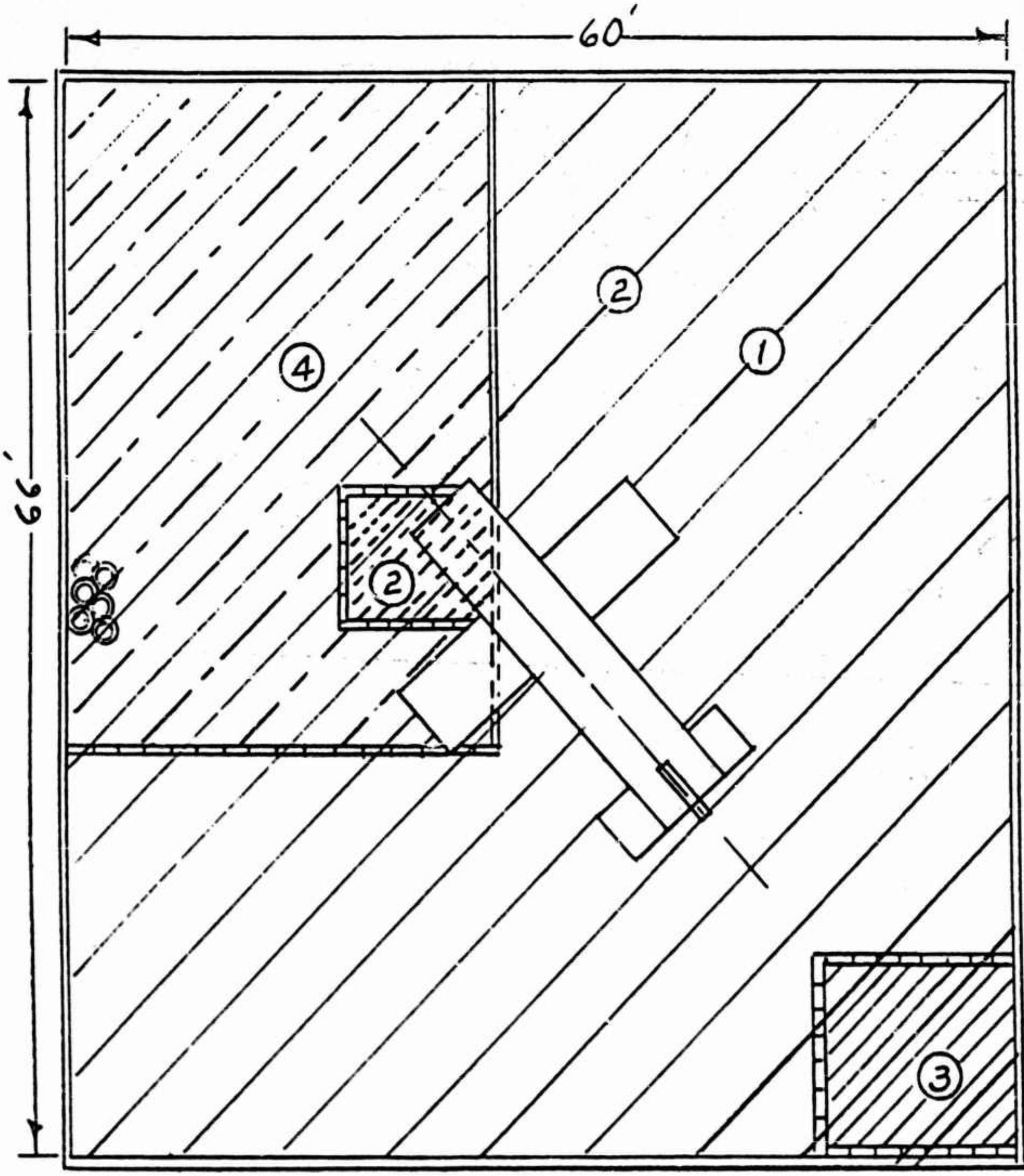
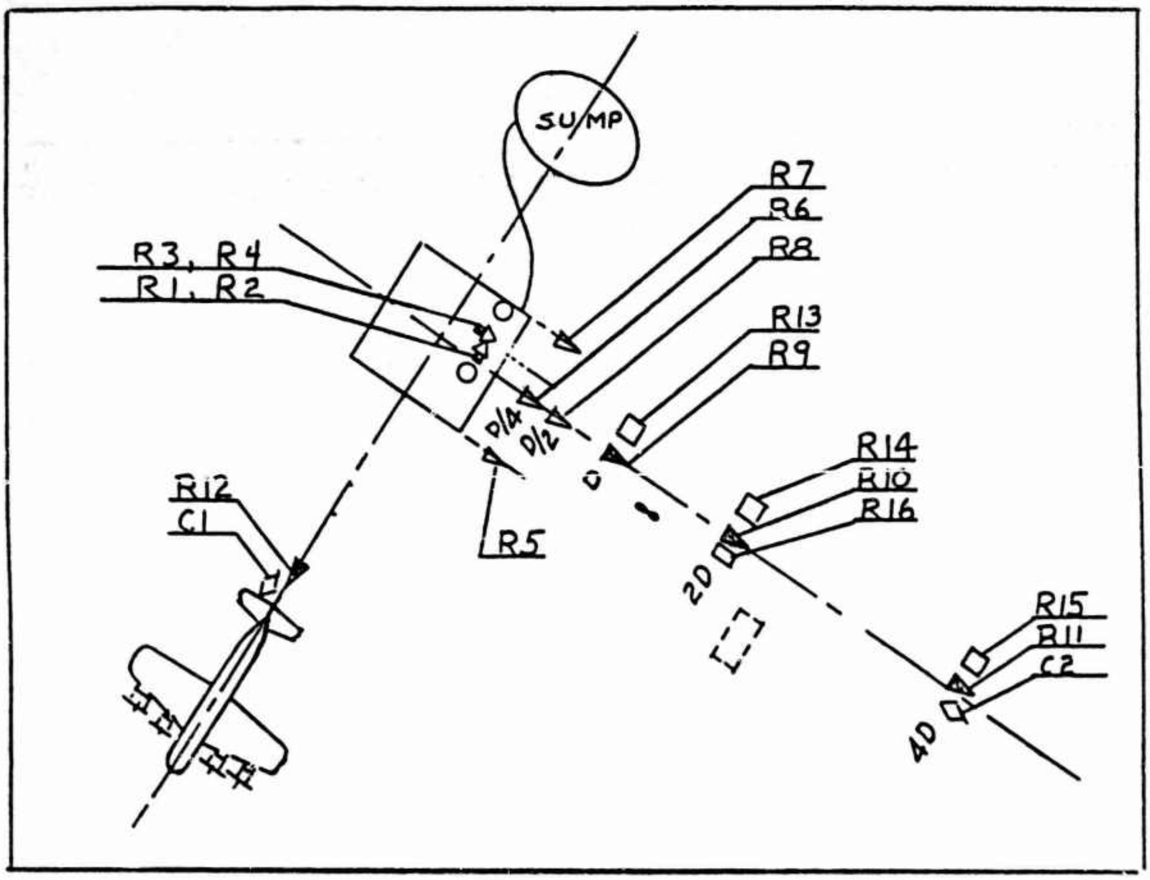


FIGURE 2.0 FUEL CONFIGURATIONS



Moffett & bare Hy-Cal radiometer pair

Hy-Cal radiometers (3 sapphire & 1 saran windows)

Thermopile radiometers (saran windows)

Beckman-Whitney radiometers

Telescopic radiometer pyrometer

Anamometer

8 mm cameras

Pneumatic load cells

Instrument trailer

D = 60'

FIGURE 2.1 INSTRUMENT ARRANGEMENT

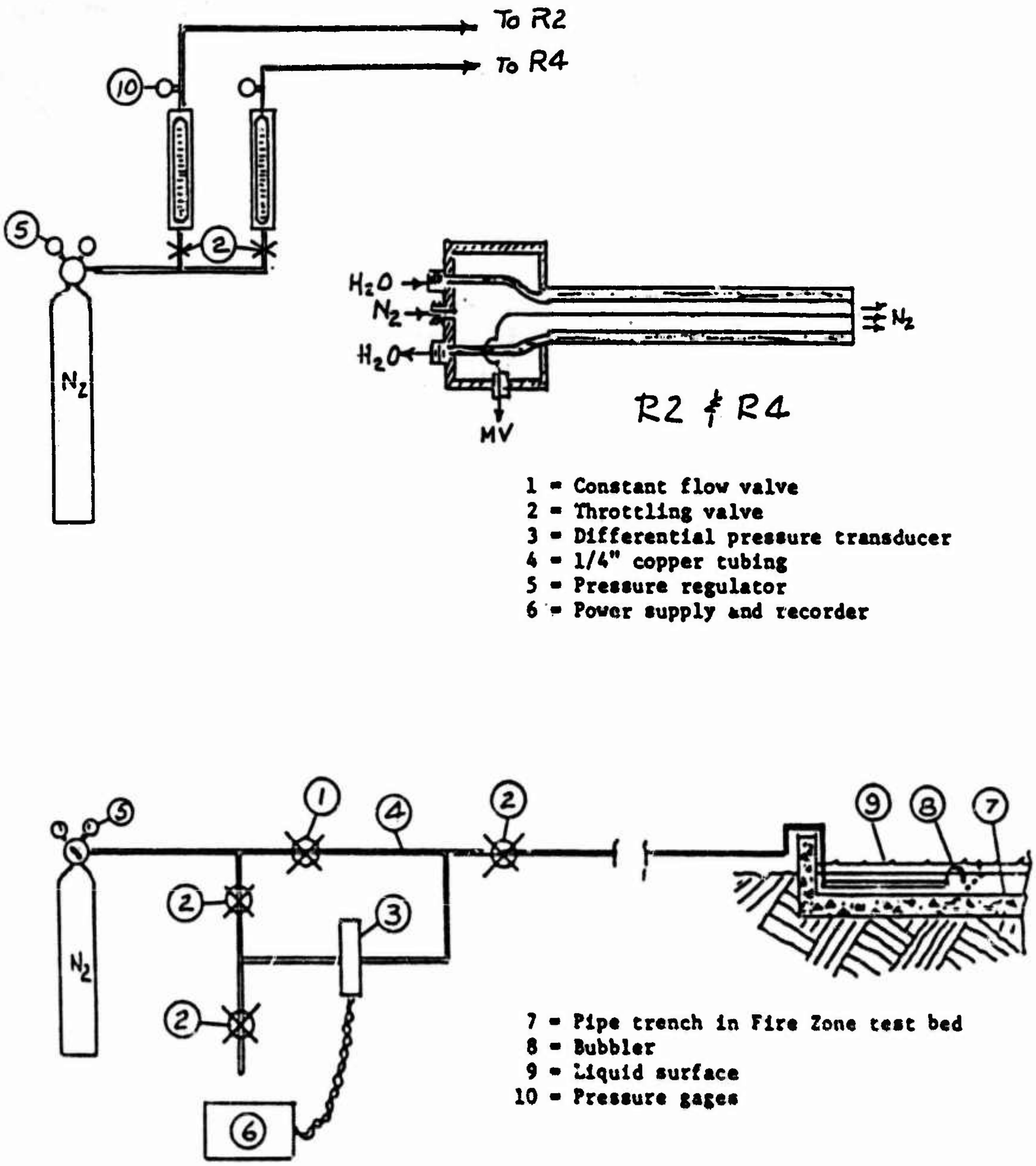
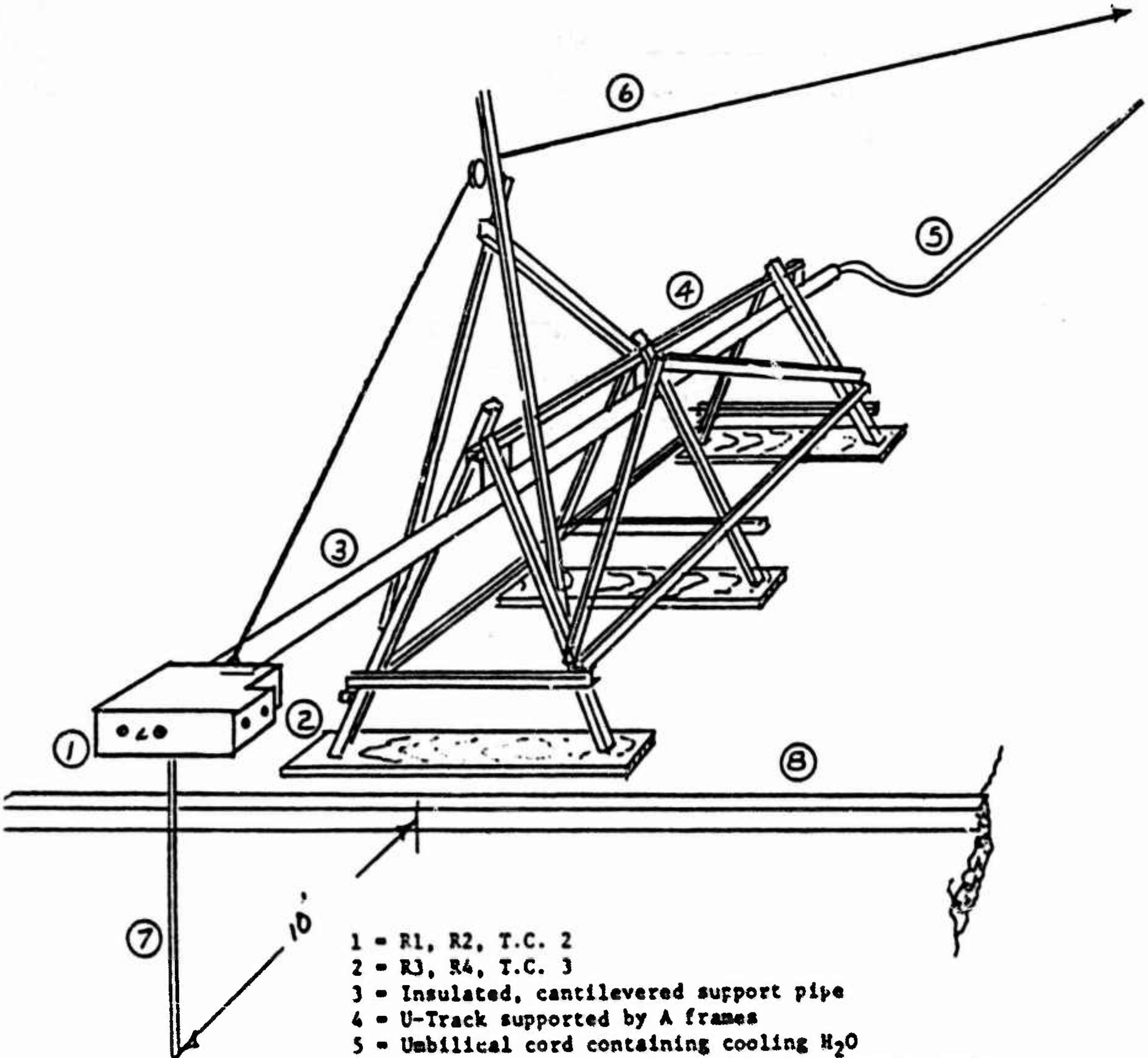


FIGURE 2.2 MOFFETT RADIOMETER AND PNEUMATIC LOAD CELL SCHEMATICS



1 = R1, R2, T.C. 2
2 = R3, R4, T.C. 3
3 = Insulated, cantilevered support pipe
4 = U-Track supported by A frames
5 = Umbilical cord containing cooling H_2O
N2 and 4 coaxial cables and 3 thermocouple leads
6 = Retraction cable
7 = Unattached support pipe
8 = Curb of test pond

FIGURE 2.3 MONORAIL SYSTEM FOR MOVABLE RADIOMETERS R1,R2,R3 & R4

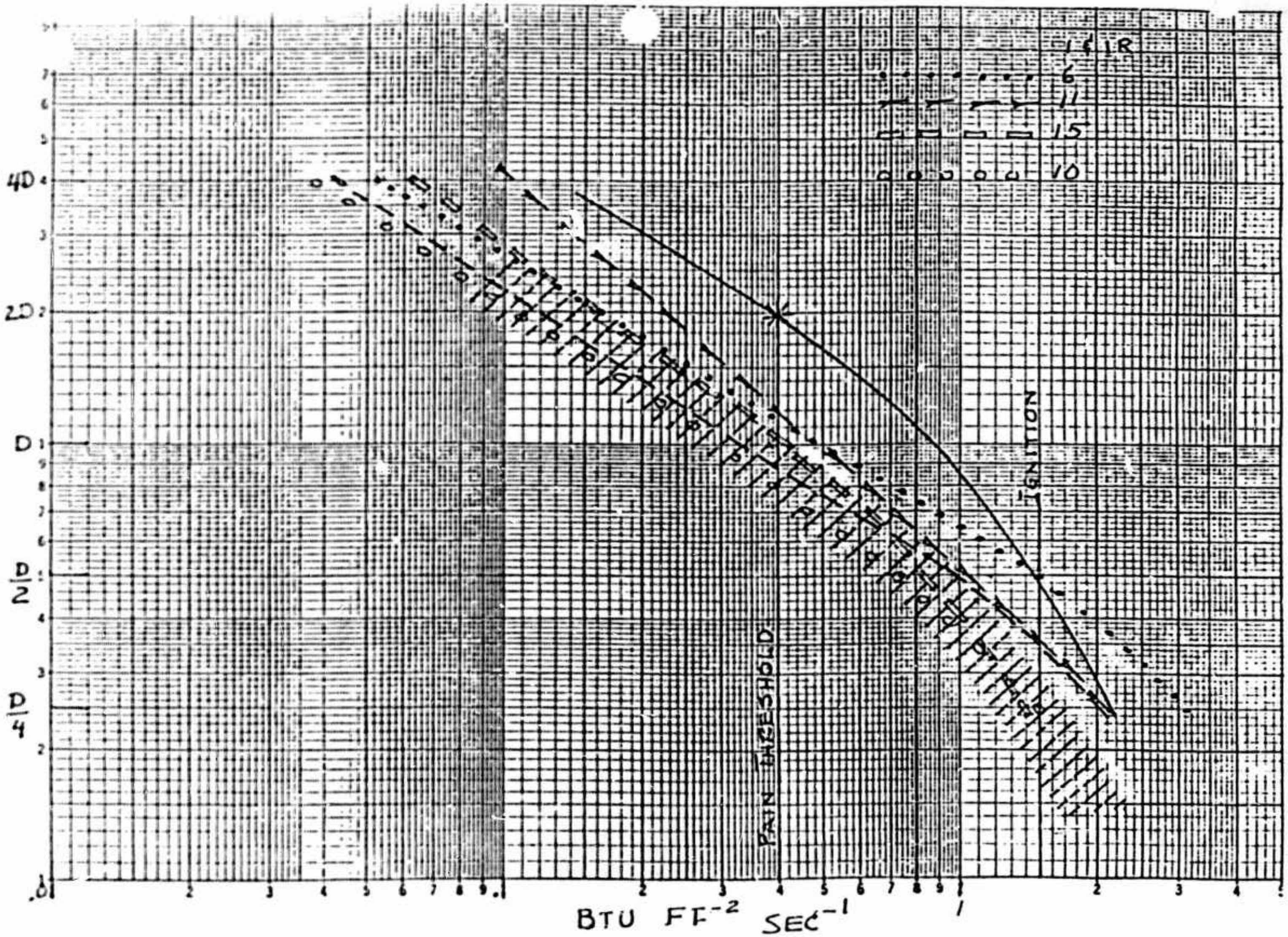


FIGURE 3.0 RADIATION FLUX AS A FUNCTION OF DISTANCE IN POOL WIDTHS D FROM BURNING JP5

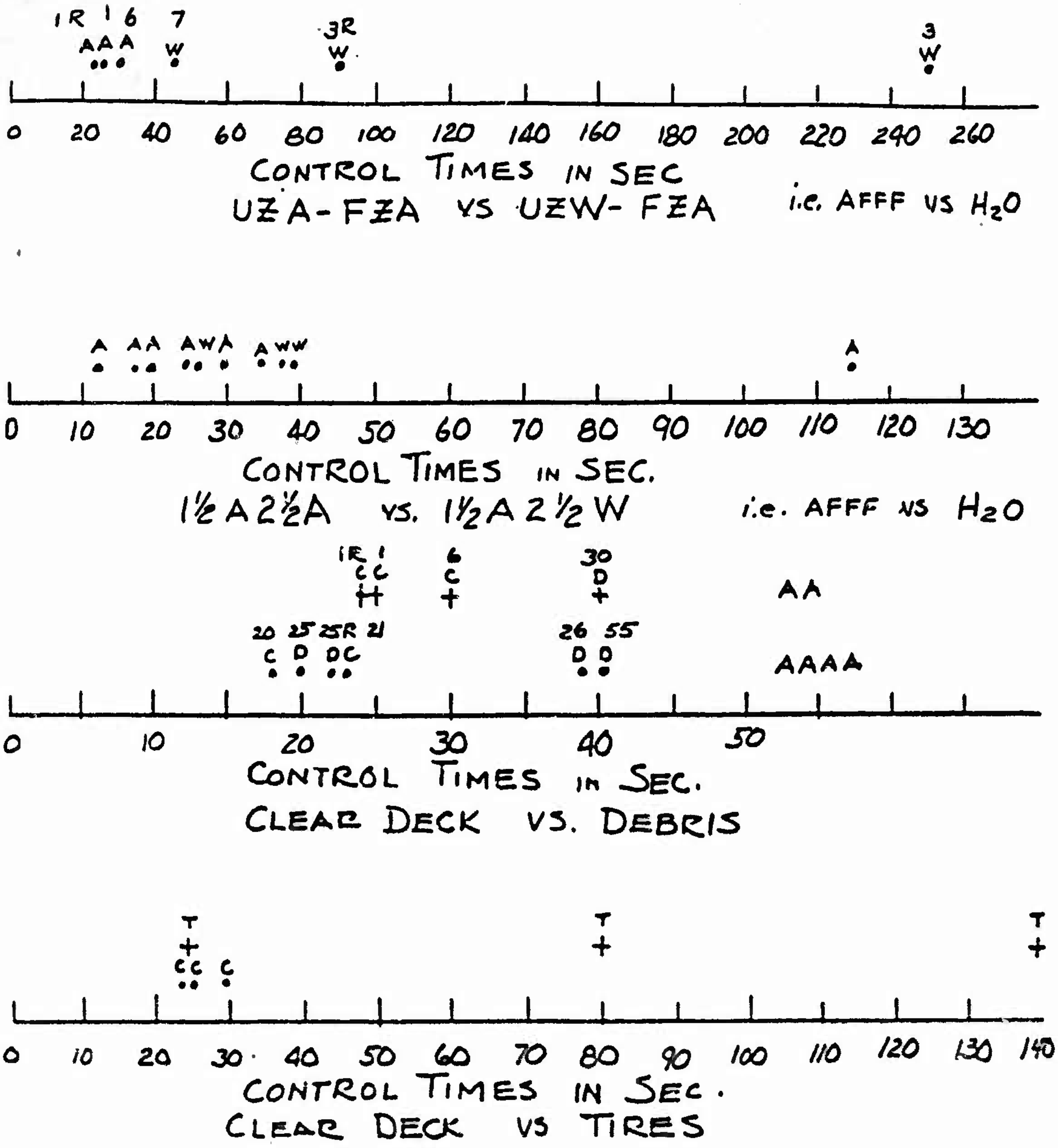


FIGURE 3.1 EFFECT OF TEST PARAMETERS ON CONTROL TIMES

SUPPLEMENTARY

INFORMATION

AD-A178 554

June 12, 1987

ERRATA

To: Distribution list for NRL Memorandum Report 5952, "Aircraft Carrier Flight Deck Fire Fighting Tactics and Equipment Evaluation Tests," by Homer W. Carhart, Joseph T. Leonard, Robert L. Darwin, Robert T. Burns, J. Thomas Hughes, and E. J. Jablonski, dated February 26, 1987.

The following changes should be made:

replace pp. 117-120 with attached pages.

Table B-1. Stream Reach Data (using straight stream)

FLOW (GPM)	STANG MONITOR (diameter in in.)	NOZZLE DIAMETER (in.)	NOZZLE PRESSURE (PSI)	ELEV. ANGLE	TEST NUMBER	WIND SPEED (kts)	DISCHARGE ANGLE WITH RELATION TO WIND DIRECTION (ft) WITH	INTO	CROSS	10°	30°	60°	COMMENTS
425	3	1-1/8	80	0°		30		72	48		53	42	
715	3	1-1/2 stack	80	0°		30		81	41		56	45	
930	3	1-3/4 stack	80	0°		30		85	45		58	46	
1,000	3	1-3/4	120	0°	14	30		155	65		55	70	
1,000	3	1-3/4	120	0°	16	30			65		65	80	
1,000	3	1-3/4	120	30°	32	30				150	160		
1,000	3	1-3/4	200	0°	33	30		160			220		
1,000	3	1-3/4	200	30°	33	30	180			160			
1,000	3	1-3/4	120	0°	34	30	180		70		70	80	
1,000	3	1-3/4	120	30°	34	30	220		80				
1,000	3	1-1/2 stack	225	0°	18	30			40		3C	65	
1,000	4	1-7/8	100	0°	37	0	90						
1,000	4	1-7/8	100	30°	37	0	210						130-210 ft rain
1,000	4	1-7/8	100	40°	37	0	200						130-200 ft rain
1,000	4	1-7/8	200	30°	52	0	545						360-545 ft rain
1,050	3	1-3/4	125	0°	27	0	150						
1,085	3	2	80	0°		30		75	70		63	68	
				10°		30		81	64		67	65	
1,100	3	1-1/2 stack	225	0°	25	0	120-160						very broken
				30°	25		195-245						drifting
1,200	3	2-stack	80	0°	30			89	40		54	48	
				10°	30			120	47		58	46	
1,250	3	1-3/4	200	0°	17	30		75	80			90	
1,300	3	1-3/4	200	0°	26	0	240						broken
				30°	26		245						broken

FLOW (GPM)	STANG MONITOR (diameter in in.)	NOZZLE DIAMETER (in.)	NOZZLE PRESSURE (PSI)	ELEV. ANGLE	TEST NUMBER	WIND SPEED (kts)	DISCHARGE ANGLE WITH RELATION TO WIND DIRECTION (ft)						COMMENTS
							WITH	INTO	CROSS	10°	30°	60°	
1,500	4	1-7/8	200	0°	38	0	100						
				30°			340						
				40°			280						
1,500	4	2-1/4	108	0°	42	0	70						
				10°	42	0	160						rain entire length
				20°			220						rain entire length
				30°			250						200-250 ft rain
1,500	4	2-1/4	108	0°	43	0	90						short streams
				10°			170						
				20°			230						rain entire length
				30°			250						
1,500	4	2-1/4	108	0°	44	0	100						100-170 ft rain
				10°			170						
				20°			230						rain entire length
				30°			230						
1,500	4	2-1/4	108	0°	45	0	80						
				10°			210						180-210 ft rain
				20°			290						250-290 ft rain
				30°			300						250-300 ft rain
1,530	3	2-1/4	80	0°		30		101	87		83	91	
				10°		30		140	123		108	103	
2,000	3	2-1/4	180	0°	21	30			75		75	90	
2,000	3	2-1/4	180	0°	7	0	200						
				30°			285						
2,000	3	2-1/2	115	0°	28	30		95					
				30°				180			200		part out of wind
				30°	29	30		200					
2,000	3	2-1/2	110	0°	35	30	160		100		90	100	
				30°			310		130				
2,000	3	2-1/2	110	0°	39	0	100						
				10°			240						
				20°			340						260-340 ft rain
				30°			340						250-340 ft rain
2,000	3	2-1/2	115	0°	4	30			65		70	100	
2,000	3	2-1/2	120	0°	15	30		180	100		95	100	

FLOW (GPM)	STANG MONITOR (diameter in in.)	NOZZLE DIAMETER (in.)	NOZZLE PRESSURE (PSI)	ELEV. ANGLE	TEST NUMBER	WIND SPEED (kts)	DISCHARGE ANGLE WITH RELATION TO WIND DIRECTION (ft) WITH	INTO	CROSS	10°	30°	60°	COMMENTS
2,020	3	2-1/2	80	0°		30		98	95		95	93	
				10°		30		140				116	
2,300	3	2-1/2	115	0°	24	0	235						
				30°			265						
2,300	4	2-1/2	150	0°	40	0	110						
				10°			280						rain
				20°			380						entire
				30°			350						length
2,400	4	3-1/4	60	0°	41	0	100						
				10°			220						
				20°			340						400-340 ft rain
				30°			320						200-370 ft rain
2,600	3	2-1/2	200	0°	20	30			100		90	90	
2,600	3	2-1/2	200	0°	36	30			80		130		
				30°			330		250				broken out of wind
2,900	3	2-1/2	200	0°	22	0	255						
				30°			385						
4,700	8	4	100	0°	46	0	130						
				10°			260						240-260 ft rain
				20°			360						330-360 ft rain
				30°			425						365-425 ft rain
				38°			400						350-400 ft rain
6,600	8	4	185	0°	47	0	200						
				10°			350						300-350 ft rain
				20°			380						300-380 ft rain
				30°			460						300-460 ft rain
				38°			460						300-460 ft rain
10,250	10	5	220	20°	50	0	370						310-370 ft rain
10,500	10	5	230	30°	51	0	545						360-545 ft rain
11,000	10	5	240	10°	49	0	370						310-370 ft rain
11,200	10	5	--	10°	48	25			190				

ESTIMATED EFFECTIVE STREAM REACH AGAINST 30 KNOTS WIND